4. ENVIRONMENTAL IMPACTS

This Chapter of the Draft Environmental Impact Statement (DEIS) for the Mars Surveyor 2001 Mission presents information on the potential environmental impacts of the Proposed Action and the alternatives to the Proposed Action. The impacts are examined for three areas: (1) the region surrounding Cape Canaveral Air Station (CCAS), FL; (2) the region surrounding Vandenberg Air Force Base (VAFB), CA; and (3) the global environment.

4.1 ENVIRONMENTAL IMPACTS OF THE PROPOSED ACTION

NASA proposes to continue preparations for and to implement the Mars Surveyor 2001 (MS 01) Mission. The MS 01 mission consists of two spacecraft launched from two separate launch sites: (1) an orbiter spacecraft launched on board a Delta II 7925 from VAFB's Space Launch Complex (SLC)-2 in March/April 2001; and (2) a lander/rover spacecraft launched on board a Delta II 7425 from Launch Complex (LC)-17 at CCAS in April 2001.

As described in Section 2.1.1, the MS 01 orbiter would carry a Gamma Ray Spectrometer (GRS) to complete the elemental mapping of the Martian surface as well as additional science payloads to perform a suite of remote scientific observations of the planet. The MS 01 orbiter would also serve as a data relay for the lander/rover.

The lander/rover would perform scientific exploration of the Martian surface at the selected landing site. Two science instruments on the lander would be equipped with sealed radioactive instrument sources: a Mössbauer Spectrometer would employ 1.30×10^{10} becquerels (Bq) (350 millicuries (mCi)) of cobalt-57 (Co–57) and a radiation monitor would use up to 7.40×10^{5} Bq (20 microcuries (μCi)) of curium–242 (Cm–242). The engineering model, upgraded for flight, of the Mars Pathfinder *Sojourner* rover would be used and would employ two science instruments containing radioactive material: the Alpha-Proton X-ray Spectrometer (APXS), which would use up to 3.70×10^{12} Bq (100 mCi) of curium–244 (Cm–244) and a dust monitor, which would employ up to 1.11×10^{6} Bq (30 μCi) of americium–241 (Am–241). The rover would also use three radioisotope heater units (RHUs) for thermal control. RHUs provide a passive source of heat from the radioactive decay of plutonium dioxide (mostly Pu-238, a non-weapons grade plutonium isotope). Each RHU contains 2.7 grams (0.006 lb) of plutonium dioxide with an activity level of about 1.23×10^{12} Bq (33.2 curies (Ci)), for a total RHU activity of about 3.69×10^{12} Bq (99.6 Ci) on the rover.

The nonradiological environmental impacts associated with Delta II launches from both CCAS and VAFB have been addressed in previous NEPA documentation and are summarized here in Sections 4.1.1 and 4.1.2. The principal documentation summarized includes: NASA's *New Millennium Program Final Programmatic Environmental Assessment* (NASA 1998a); the *Stardust Mission Environmental Assessment* (NASA 1998b); and the *U.S. Air Force Final Environmental Impact Statement – Evolved Expendable Launch Vehicle Program* (USAF 1998).

4.1.1 Environmental Impacts of Preparing for the MS 01 Launches

Launch vehicle and payload processing at both CCAS and VAFB typically involve a number of industrial activities and include the use of hazardous materials. Hazardous, solid, and liquid wastes and air emissions would be handled as described in Sections 2.1.5 and 2.1.6. Processing of the launch vehicles for the MS 01 mission would entail activities common to all Delta II launches at CCAS and VAFB and have been addressed in existing NEPA documentation. Launch vehicle processing activities are subject to Federal, State, and local environmental laws and regulations and U.S. Air Force regulations and requirements. No new environmental licenses or permits would be required for the MS 01 mission at either launch site.

Airborne emissions from liquid propellant loading and off-loading of the spacecraft and the launch vehicle are closely monitored using vapor detectors. Hypergolic fueling systems utilize state-permitted air emission controls (scrubbers and closed loop systems).

Some spacecraft and launch vehicle integration personnel at CCAS could be exposed to external radiation hazards during normal ground processing and launch preparation activities for the MS 01 mission. Additionally, there could be ground or launch processing accident conditions that could cause a localized (i.e., within the processing facility or area) release of radioactive material from the small quantity radioactive sources. While this could result in occupational exposures to small quantities of Cm–244, Cm–242, Co–57, or Am–241, there are no facility accident conditions that could cause such a release of the plutonium contained in the RHUs.

Integration and launch processing activities involving radioactive materials at KSC/CCAS are subject to extensive review and authorization of all activities by the local radiation protection authority prior to initiation of any operation (KSC 1996). Such operations are actively monitored by launch site radiation safety professionals to ensure adherence to approved operating and emergency procedures and to maintain operational personnel exposures at levels that are as low as reasonably achievable.

4.1.2 Environmental Impacts of a Normal MS 01 Launch

The primary environmental impacts of a normal launch of the two MS 01 spacecraft from both CCAS and VAFB would be associated with airborne emissions from the strap-on graphite epoxy solid rocket motors (GEMs). For the purposes of this Mars 2001 Mission DEIS, the impacts associated with the normal launch of a Delta II 7925 with its nine GEMs at VAFB would be expected to exceed the environmental impacts associated with a Delta II 7425 launch vehicle with four GEMs. The Delta II 7925 will serve as the basis for analysis of nonradiological environmental impacts. Because the orbiter and lander/rover launches would occur at different launch sites, environmental impacts are described for each launch site.

4.1.2.1 Land Use

Use of land areas on and around LC-17 at CCAS and SLC-2 at VAFB would be entirely consistent with the uses designated for the two launch complexes and for CCAS and VAFB.

4.1.2.2 Air Quality

Rocket launches are discrete events that cause short-term impacts on local air quality. However, because launches are relatively infrequent events, and winds rapidly disperse and dilute the launch emissions to background concentrations, long-term effects from exhaust emissions would not be anticipated.

Rocket motor emissions from the two MS 01 launches would form a cloud at their respective CCAS and VAFB launch pads during the first few seconds after ignition and liftoff. This high-temperature cloud would be buoyant, would rise quickly, and would tend to stabilize at an altitude of a few hundred meters near each launch area. The cloud would then dissipate through mixing with the atmosphere. Exhaust products would be distributed along each vehicle's flight path, but emissions per unit length of trajectory would decrease as each vehicle accelerates.

The first stage liquid propellant engine, fueled by rocket propellant (RP-1) and liquid oxygen, would produce primarily carbon monoxide (CO), carbon dioxide (CO_2), and water as combustion products (USAF 1998). The solid rocket fuel in the GEMs, consisting of ammonium perchlorate, aluminum powder and binder (hydroxyl-terminated polybutadiene (HTPB)), would oxidize primarily into aluminum oxide particulates (Al_2O_3), CO, hydrogen chloride (HCl), and nitrogen. Carbon monoxide and nitrogen would be expected to quickly oxidize into carbon dioxide and nitrogen oxides, respectively. Table 4-1 provides the total first stage emissions for the Delta II 7925 and the Delta II 7425.

<u>CCAS</u>. <u>Lower Atmosphere</u>. While the MS 01 lander/rover spacecraft would be launched from CCAS on a Delta II 7425, the launch of a Delta II 7925 used in prior NASA NEPA documentation (NASA 1998a) will be addressed here as a bounding case. The U.S. Air Force's Rocket Exhaust Effluent Diffusion Model (REEDM) was used to predict short-term concentrations of pollutants. Meteorological conditions used in the modeling resulted in transport of the exhaust emissions across land.

The model predicted both peak concentrations of exhaust constituents as well as the highest expected mean 60-minute concentrations. The peak Al_2O_3 particulate level was predicted at 3,071 micrograms per cubic meter ($\mu g/m^3$) at a distance of 10 kilometers (km) (6 miles (mi)) downwind of LC-17. The peak levels of CO and HCl (1.758 parts per million (ppm) and 0.792 ppm, respectively) were predicted to occur 13 km (8 mi) downwind of the launch complex (NASA 1998a).

TABLE 4-1. TOTAL EMISSIONS FROM TYPICAL DELTA II LAUNCH VEHICLES (FIRST STAGE AND GEMS)

Constituents	Delta II 7925		Delta II 7425	
	kg	tons	kg	Tons
Carbon monoxide (CO)	64,643	71	51,682	57
Aluminum oxide (Al_2O_3)	37,900	42	16,845	19
Water (H_2O)	33,363	37	28,825	32
Carbon dioxide (CO_2)	31,183	34	29,804	33
Hydrogen chloride (HCl)	22,284	24	9,904	11
Nitrogen (N_2)	8,696	10	3,865	4
Hydrogen (H_2)	3,751	4	2,413	3
Hydroxide ion (OH^-)	40	<<1	27	<<1
Chlorine (Cl)	285	<1	128	<1
Hydrogen (H)	31	<<1	18	<<1
Aluminum (1) chloride (AlCl)	21	<<1	19	<<1
Aluminum (2) chloride ($AlCl_2$)	21	<<1	8	<<1
Aluminum (3) chloride ($AlCl_3$)	11	<<1	4	<<1
Aluminum (1) chlorate (AlClO)	11	<<1	4	<<1
Total	202,240	222	143,540	159

Source: adapted from NASA 1998b

NOTE: Emission masses calculated assuming combustion of entire fuel load, conservation of mass, and no atmospheric contribution to emissions. Masses do not total to the propellant quantities listed in Section 2.1.6 due to rounding.

Predicted Al_2O_3 particulates and HCl levels are compared in Table 4-2 to the Emergency Response Planning Guidelines (ERPG) developed by the American Industrial Hygiene Association. These guidelines are the maximum airborne concentrations below which it is believed that nearly all individuals could be exposed for up to 1 hour without experiencing health effects (ERPG-1). The predicted highest mean 60-minute concentrations of particulates and HCl would be well below these guidelines.

CCAS is in an attainment area for all National Ambient Air Quality Standard (NAAQS) pollutants.

Airborne emissions from a normal launch at CCAS are not expected to result in adverse impacts to the off-site public. The nearest public area from LC-17 is about 6 km (4 mi) (NASA 1998a).

Each of the two MS 01 launches would also deposit small amounts of water (H_2O) and carbon dioxide (CO_2) into the troposphere. These are common “greenhouse” or “global warming” gases. The amounts of these materials deposited into the troposphere by rocket launches have been estimated to contribute only minutely to global warming, representing 4×10^{-5} to 5×10^{-7} percent of total CO_2 produced and emitted globally

TABLE 4-2. PREDICTED PEAK AND HIGHEST 60-MINUTE MEAN CONCENTRATIONS OF EXHAUST PRODUCTS FROM A TYPICAL LAUNCH OF A DELTA II 7925 AT CCAS

Ground Level Exhaust Cloud Constituent	Peak Concentration in ppm except where noted	Highest 60-Minute Mean Concentration in ppm except where noted	Distance at which Peak/Mean Concentrations Occur in km (mi)	ERPG[a] ppm except where noted			National Ambient Air Quality Standard
				1	2	3	
Aluminum oxide particulates (Al_2O_3)[b]	3,071 µg/m^3	91 µg/m^3	10/12 (6/7)	15,000 µg/m^3	15,000 µg/m^3	25,000 µg/m^3	<u><10 microns</u> 24-hr avg.= 150 µg/m^3 <u><2.5 microns</u> 24-hr avg.= 65 µg/m^3
Carbon monoxide (CO)	1.758	0.065	13/16 (8/10)	NA[c]			1-hr avg. = 35 ppm
Hydrogen chloride (HCl)	0.792	0.029	13/16 (8/10)	3	20	100	NA

Source: NASA 1998a

a. ERPGs (Emergency Response Planning Guidelines) are developed by the American Industrial Hygiene Association. They represent the maximum airborne concentration below which it is believed nearly all individuals could be exposed for up to one hour without (1) experiencing adverse health effects (ERPG-1); (2) perceiving clearly defined objectionable odor (ERPG-2); or (3) experiencing or developing life-threatening health effects (ERPG-3).
b. Aluminum oxide (Al_2O_3) concentrations are given in µg/m^3 because the aluminum oxide is a solid rather than a gas.
c. NA = not applicable, or no standard available.

(AIAA 1991), and the water produced being on the order of a few thousandths of a percent of that naturally released to the atmosphere in the tropics (Wayne 1991).

Upper Atmosphere. For the upper atmosphere, the Delta II 7925 is taken as a bounding case because it has a greater number of GEMs than the Delta II 7425 and so would have a greater quantity of exhaust products. The Delta II 7925 six ground-lit GEMs would burn out and jettison at an altitude of 28 km (15 nautical miles (nmi)) after 86 seconds of flight. Thus a substantial portion of the ground-lit emissions would be in the troposphere and subject to photochemical oxidation and rain out. The three air-lit GEMs would burn largely in the stratosphere. The Delta II 7925 ozone depletion estimate (see Appendix E), however, conservatively assumed all emissions migrate to the stratosphere and thus represent an upper limit (in fact, a large portion of the emissions would remain in the troposphere): 22,498 kg (24.8 tons) of HCl, 38,192 kg (42.1 tons) of Al_2O_2, and 8,709 kg (9.6 tons) of NO_x. The estimated percent reduction in annually averaged global total ozone would be 1.03×10^{-3} percent (see Appendix E).

VAFB. Lower Atmosphere. Using REEDM at VAFB, the Air Force modeled the launch of a Delta II 7925 under no wind shear meteorological conditions resulting in high ground-level particulate deposition (NASA 1998a).

The peak concentration of Al_2O_3 was predicted to reach 49,100 $\mu g/m^3$ at a distance of about 3 km (2 mi) downwind of SLC-2. Carbon monoxide and HCl were predicted to peak at a distance of 10 km (6 mi) downwind, at levels of 1.76 ppm and 0.79 ppm, respectively. The predicted highest 60-minute mean concentrations and the distances downwind of SLC-2 are provided in Table 4-3. The predicted highest mean 1-hour levels of HCl and particulate matter were well below ERPG guidelines. Airborne emissions from a normal launch at VAFB would not be expected to result in adverse impacts to the off-site public. The VAFB fence line is located about 11 km (7 mi) away; base housing is located 8 km (5 mi) away.

Because Santa Barbara County is in “serious” nonattainment for ozone, section 176 (c) of the Clean Air Act “the General Conformity Rule” applies to VAFB actions and activities. Specifically, this means that activities undertaken at VAFB that would result in nonattainment criteria emissions will not (1) cause or contribute to new violations of a NAAQS, (2) increase the frequency or severity of existing violation of a NAAQS; and (3) delay the timely attainment of a NAAQS.

Launch of the MS 01 orbiter constitutes a single launch among the normal complement of Delta II and other launches that occur each year at VAFB. A 1996 analysis associated with increasing Delta II launches at VAFB from 2 to 10 per year concluded that the requirements of a conformity analysis were not applicable to the increase in launch rate (MDA 1996). Thus, given that the MS 01 launch would be part of the normal number of Delta II launches from VAFB in 2001, it would not be expected to contribute to, or cause, exceedances in the emission of ozone precursors at VAFB. This is further indicated by comparing the anticipated total emissions of ozone precursors associated with the launch (volatile organic carbons (VOCs) and oxides of

TABLE 4-3. PREDICTED PEAK AND HIGHEST 60-MINUTE MEAN CONCENTRATIONS OF EXHAUST PRODUCTS FROM A TYPICAL LAUNCH OF A DELTA II 7925 AT VAFB

Ground Level Exhaust Cloud Constituent	Peak Concentration in ppm except where indicated	Highest 60-Minute Mean Concentration in ppm except where indicated	Distance at which Peak/Mean Concentrations Occur in km (mi)	ERPG[a] ppm except where indicated			National Ambient Air Quality Standard	California Ambient Air Quality Standard
				1	2	3		
Aluminum oxide particulates (Al_2O_3)[b]	49,100 μg/m^3	7,290 μg/m^3	3/4 (2/3)	15,000 μg/m^3	15,000 μg/m^3	25,000 μg/m^3	<10 microns 24-hr avg.= 150 μg/m^3 <2.5 microns 24-hr avg.= 65 μg/m^3	<10 microns 24-hr avg.= 50 μg/m^3 <2.5 microns Same as NAAQS
Carbon monoxide (CO)	1.76	0.62	10/14 (6/9)	NA[c]			1-hr avg. = 35 ppm 8-hr avg. = 9 ppm	1-hr ave. = 20 ppm
Hydrogen chloride (HCl)	0.79	0.28	10/14 (6/9)	3	20	100	NA	NA

Source: NASA 1998a

a. ERPGs (Emergency Response Planning Guidelines) are developed by the American Industrial Hygiene Association. They represent the maximum airborne concentration below which it is believed nearly all individuals could be exposed for up to one hour without (1) experiencing adverse health effects (ERPG-1); (2) perceiving clearly defined objectionable odor (ERPG-2); or (3) experiencing or developing life-threatening health effects (ERPG-3).

b. Aluminum oxide (Al_2O_3) concentrations are given in μg/m^3 because the aluminum oxide is a solid rather than a gas.

c. NA = not applicable, or no standard available.

nitrogen (NO_X)) with the de minimus threshold for VOC and NO_x of 43 metric tons/yr (50 tons/yr) for each established by the Santa Barbara County Air Pollution Control District Regulation VII Rule 202, and with the threshold for determining if the emissions would be regionally significant (10 percent of the annual emission inventory within the nonattainment area for VOCs and NO_X).

Using data prepared by the U.S. Air Force for its next generation of launch vehicles (USAF 1998), the total emissions of VOC and NO_X for a single Delta II launch event can be estimated for all launch and launch-related activities (preparation, assembly, and fueling; mobile sources; point sources; and launch). Utilizing this information, the anticipated total VOC emissions associated with the MS 01 launch would be about 1.1 metric tons (1.2 tons), and 5.2 metric tons (5.7 tons) for NO_x. These levels are a small fraction of the de minimus levels. Looking at the 10 percent annual thresholds, the emissions inventory for the region (SBCAPCD 1998) projected to the year 2005 yields a 10 percent threshold of 1,062 metric tons/yr (1,170 tons/yr) for VOC and 1,149 metric tons/yr (1,266 tons/yr) for NO_x. The anticipated total ozone precursor emissions associated with the Mars 01 launch at VAFB noted above would be a small fraction of the 10 percent thresholds.

Upper Atmosphere. The MS 01 orbiter mission would be launched on a Delta II 7925 from VAFB. See the upper atmosphere described for CCAS in Section 4.1.2.2 for a detailed discussion of Delta II 7925 emission influences on stratospheric ozone and global climate change. See Appendix E for details.

4.1.2.3 Noise

Noise impacts associated with launches occur due to sound reflected from the launch pad from ignition though liftoff. Increased noise levels would occur for only a short period during the launch (less than two minutes), diminishing rapidly as the launch vehicle gains altitude and moves downrange (USAF 1998).

Sonic booms would occur in offshore areas at both CCAS and VAFB (NASA 1998a; NASA 1998b; USAF 1998). Given that the sonic booms would occur over the ocean and downrange of populated areas, no adverse impact to human populations would be expected. Ships and other vessels in the area potentially affected would be warned in advance of launch events and would not expected to be adversely affected.

CCAS. Based on noise measurements taken for a 1992 Delta II launch at LC-17, noise levels were predicted to be about 98 decibels (dBA) in the City of Cape Canaveral, about 6 km (4 mi) to the south of LC-17, and about 88 dBA to 93 dBA at the southeast portion of Merritt Island, about 8 km (5 mi) from the launch complex (USAF 1996). Launch site workers would be a minimum of 2,000 m (6,500 ft) away from LC-17 at the time of launch and would be exposed to noise levels of less than 110 dBA, well below Occupational Safety and Health Administration regulations for unprotected workers (140 dBA maximum; 115 dBA 15 minute average). While some area residents may experience momentary annoyance, the noise levels outside the CCAS property boundary would not exceed U.S. EPA's maximum 24-hr average exposure level of 70 dBA and would present no health hazard.

VAFB. Short-term noise levels at the time of launch in the communities closest to VAFB (Lompoc, about 16 km (10 mi) to the southeast of SLC-2, and Santa Maria, about 24 km (15 mi) to the northeast) would be below 94 dBA and would not exceed the
U.S. EPA maximum 24-hr average exposure level of 70 dBA for the general public (NASA 1998a). Dependent on the flight azimuth, sonic booms could occur at the Channel Islands, southwest of VAFB following the Delta II launches. Potential impacts to wildlife are discussed in 4.1.2.7.

4.1.2.4 Geology and Soils

No adverse impacts to geology and soils at CCAS and VAFB would be expected from a launch. Primary exhaust products from the launch, Al_2O_3 particulates and HCl gas from the GEMs, would be dispersed depending upon particle size distribution and wind conditions. Aluminum would largely contribute as fugitive dust. Given the buffering capacity of soils surrounding the launch pads, no adverse impacts to geology and soils would be anticipated.

CCAS. No adverse impacts to the underlying geology would be expected at CCAS. Wet deposition of HCl would occur near the launch pad from mixing of chlorides with entrained deluge water and with water contained in the exhaust of the first stage liquid propellant engine. Wet deposition would be limited to within a few hundred meters of the launch pad. If a rainstorm passed through the exhaust ground cloud shortly after launch, wet HCl deposition could occur at further distances from the launch complex. The soils at CCAS have relatively high buffering capacities and are not expected to be adversely affected (NASA 1998b).

VAFB. No impacts to the underlying geology would be expected at VAFB. The soils at VAFB have relatively high buffering capacities and are not expected to be adversely affected (NASA 1998a).

4.1.2.5 Hydrology and Water Quality

There are two principal sources of potential impacts to groundwater and surface water resources and water quality associated with a normal launch: disposal of the spent deluge water collected at the launch pad and launch pad washdown water, and the deposition of launch exhaust products from the exhaust cloud into nearby surface water bodies.

CCAS. Groundwater. At CCAS, the deluge and washdown water collected in the catchment basin of LC-17 would be monitored for water quality (NASA 1998a; NASA 1998b; USAF 1996). The water would be held and treated, if necessary, to reduce contaminant levels prior to release to grade in accordance with a Florida Department of Environmental Protection wastewater discharge permit. The water discharged to grade would percolate through soil to groundwater. The water would be neutralized during its passage through the soil, and some of the contaminants that would not be removed during treatment would also be removed. It is not expected that groundwater quality would be substantially affected by the discharge of deluge and washdown water.

Surface Water. Depending on wind conditions, the launch exhaust cloud could drift over the Atlantic Ocean or the Banana River near CCAS. Surface waters in the area of the exhaust cloud might acidify from deposition of HCl if a rainstorm passed through the exhaust cloud (USAF 1996; USAF 1998). The large volumes of water bodies in the vicinity of CCAS, combined with their natural buffering capacity, suggest that the reduced pH caused by acidic deposition would return to normal levels within a few hours. Al_2O_3 particulates would also settle from the exhaust cloud. Al_2O_3 particulates are relatively insoluble at the pH of local surface waters, and would settle out of the water column to sediments. Long-term elevation of aluminum levels in the water column would not be expected.

VAFB. Groundwater. At VAFB, groundwater quality would not be appreciably affected by launch activities at SLC-2. Large amounts of water would not come in contact with pervious soils at VAFB because deluge water is discharged to sewers, not to grade. Supplies from the State Water Project now supplement water supply from the local aquifers. As such, the MS 01 orbiter launch would not adversely impact groundwater supplies.

Surface Water. At VAFB, the exhaust cloud from a Delta II launch at SLC-2 could drift over Shuman Creek, San Antonio Creek, Santa Ynez River, or the Pacific Ocean, depending on wind direction and speed immediately following launch. In general, however, there would be little wet deposition of HCl at these distances from the launch complex. Wet deposition would occur away from the launch complex only if a rainstorm were to pass through the exhaust cloud, an infrequent event at VAFB. Even if wet deposition occurred, changes in pH in near shore oceanic waters are expected to be small and temporary because of the large volume of the near shore waters and the natural buffering capacity of the ocean. Short-term changes in fresh waters would probably be larger, but reduced pH waters would be transient as the streams flow to the ocean and the acid is neutralized by the streams' natural buffering capacity. Relatively insoluble, Al_2O_3 particulates from the exhaust cloud would have only short-term elevated concentrations in the water column (NASA 1998a) and would be incorporated into the sediments of the water bodies.

4.1.2.6 Offshore Environment

The offshore environment would be impacted by the jettisoned spent GEM casings and the first and second stages of the Delta II launch vehicles.

CCAS. The jettisoned launch vehicle sections would typically land in deep ocean areas where the metal parts would eventually corrode. Any residual propellants would be released to the water column. Toxic concentrations of the metals would be unlikely because of the slow rate of the corrosion process and the large volume of ocean water available for dilution (USAF 1996). The residual propellants in the GEM casings would be released slowly and should not reach toxic concentrations except in the immediate vicinity of the casings. Residual RP-1 fuel in the first stage is weakly soluble and is expected to form a localized surface film which would evaporate within hours. Propellants in the second stage are volatile, and the residuals left in the second stage are expected to disperse without entering the ocean.

VAFB. Impacts to the offshore environment near VAFB would be similar to those described for CCAS.

4.1.2.7 Biological Resources

Biological resources would be unaffected by the Delta II launches (NASA 1998b), except near the launch pads. Acidic deposition from the exhaust cloud and/or the high temperatures within the launch cloud could damage or kill biota within the immediate vicinity of the launch pad. Long-term population effects on terrestrial biota would not be expected. A study of a Titan launch at CCAS indicated that HCl levels in the exhaust cloud 2 to 3 minutes after launch were about 30 ppm, and that most of the acidic deposition occurred near the Titan launch pad (USAF 1990). The Delta II is a smaller vehicle that accelerates away from the launch area more quickly than a Titan and has a smaller ground-level exhaust cloud.

The short-term elevation of noise levels generated by the launch of a Delta II would probably disturb terrestrial biota near the launch complex but is not expected to result in long-term adverse impacts (USAF 1996).

CCAS. Terrestrial and Aquatic Biota. At CCAS aquatic biota in nearby water bodies, such as the Banana River and the near shore areas of the Atlantic Ocean, should not be adversely affected by the exhaust cloud (USAF 1996). There have been no fish kills recorded in either the Banana River or the near-shore areas of the Atlantic Ocean from a normal launch at CCAS (NASA 1998a; NASA 1998b).

Threatened or Endangered Species. The U.S. Fish and Wildlife Service (USFWS) reviewed the actions associated with Delta II launches from LC-17 and determined that they would not adversely affect Federally listed threatened or endangered species (USAF 1998).

VAFB. Terrestrial and Aquatic Biota. VAFB freshwater resources could potentially be exposed to short-term reductions in pH by acidic deposition from the exhaust cloud, but pH changes that might occur are expected to be small and of short duration. Long-term impacts to aquatic biota are not expected from the infrequent, short-term pH changes. Similarly, Al_2O_3 particulate deposition would result in only short-term elevations in aluminum concentrations in the water column, and the elevations would probably not be of sufficient magnitude or duration to impact freshwater biota. Marine resources are not expected to be affected.

Sonic booms would occur at the Channel Islands, southwest of VAFB following a Delta II launch. These islands harbor a diverse assemblage of marine mammals that might be disturbed, but not permanently harmed, by sonic booms. Pinniped (seals;

walrus) harassment permits are either in place or being obtained to accommodate the launch of Delta IIs and other launch vehicles from VAFB (NASA 1998a; USAF 1998).

Threatened or Endangered Species. At VAFB, two Federally listed bird species, the California least tern and the western snowy plover, use the beaches west of SLC-2. The U.S. FWS Biological and Conference Opinion recently addressed incidental loss (take) and temporary flushing of the least tern due to space vehicle launches from SLC-2 (USDOI 1999). Individual take permits and mitigation plans are in place. In addition, the *Lompoc yerba santa*, a plant, has been proposed for Federal listing as endangered and could be subject to fires if a launch accident were to occur.

4.1.2.8 Socioeconomics/Cultural and Historic Resources

Launch of MS 01 spacecraft elements from both CCAS and VAFB would be part of the ongoing Delta launch program.

CCAS. Launch of the MS 01 lander/rover would result in negligible impacts to socioeconomic factors such as demography, employment, transportation, public or emergency services. The MS 01 launch would not result in disproportionate adverse impacts on low-income or minority populations. See Appendix C for additional details.

LC-17 is an active launch complex and is eligible for listing on the National Register of Historic Places because of its significance as the longest continually active launch site, and its association with events that have made a significant contribution to history (USAF 1996). The Air Force has requested guidance from the State Historic Preservation Officer (SHPO) on how to best preserve the historical significance of LC-17 while it continues to serve the Nation's space program. As modifications occur to the launch complex, special care is taken to preserve historical information through documentation and collection of historical data.

VAFB. As part of the existing Delta space vehicle operations, no increase in permanent personnel would be anticipated, therefore no demographic or infrastructure changes would be expected. Cultural resources are present at and near SLC-2 (NASA 1998a). In recent consultation with the SHPO, elements of SLC-2 have been recommended as eligible for listing in the National Registry of Historic Places. No modification to the launch complex would occur as a result of the VAFB launch; therefore, no cultural impacts would be anticipated. The MS 01 launch would not result in disproportionate adverse impacts on low-income or minority populations. See Appendix C for additional details.

4.1.3 Environmental Impacts of Potential Nonradiological MS 01 Accidents

The potential environmental impacts associated with Delta II 7425 and Delta II 7925 accidents have been discussed in previous U.S. Air Force and NASA NEPA documentation and are summarized here.

A variety of accidents could occur during preparations for and launch of a Delta II expendable launch vehicle. Only two types of nonradiological accidents would potentially have off-site consequences: a liquid propellant spill during fueling operations and a launch failure. The potential consequences of these accidents are presented below.

CCAS. Liquid Propellant Spill. The most severe propellant spill accident scenario postulated entails release of the entire contents of the nitrogen tetroxide (N_2O_4) tank on a Delta II second stage during propellant transfer (NASA 1998a). Because N_2O_4 rapidly converts to NO_X in the air, toxic effects of the release would be limited to the immediate vicinity of the launch complex. Using the REEDM modeling results for a similar spill postulated for a Titan, and scaling for the Delta propellant loading, airborne levels of NO_X would be reduced to 5 ppm within about 150 m (500 ft) of the spill and to 1 ppm within about 300 m (984 ft) (NASA 1998b). Activating the launch pad deluge water system would substantially reduce the evaporation rate of the propellant, limit potential exposures in the vicinity of the spill, and in turn, reduce the amount of propellant dispersed downwind. During fueling, propellant transfer personnel would be equipped with protective clothing and breathing apparatus, and uninvolved personnel would be excluded from the area. U.S. Air Force safety requirements specify that plans and procedures be in place to protect the workforce and the public during fueling operations. (USAF 1997).

Launch Failures. A launch vehicle accident either on or near the launch pad within a few seconds of liftoff presents the greatest potential for impact to human health, principally to workers. Range Safety requirements mandate Command Safety Destruct (CSD) systems on both liquid propellant tanks and GEMs (NASA 1998b). In the event of a CSD activation, the propellant tanks and GEMs would be ruptured, and the entire launch vehicle would be destroyed. The potential short-term effects of an accident would include a localized fireball, falling fragments from explosion of the vehicle, release of uncombusted propellants and propellant combustion products, and for on-pad or very low altitude explosions, death or damage to nearby biota and brush fires near the launch pad.

Meteorological conditions resulting in transport over land areas were modeled for an on-pad accident involving combustion of Delta II 7925 liquid propellants and a near-pad accident involving combustion of GEM solid rocket fuel (NASA 1998b). In both types of accidents, release and combustion of both liquid and solid rocket fuels would be involved. In the event of a catastrophic launch failure, two types of accidents would occur. One accident would involve burning of solid propellant as would be the case with the GEMs. The second type of accident would occur when hypergolic propellants burn, as would be the case with the second stage propellants. For an on-pad accident, the principal constituent resulting from propellant burning was predicted to be CO, with a peak concentration estimated at about 8.7 ppm at a distance of 10 km (6 mi) downwind of Launch Complex 17. Nitrogen dioxide (NO_2) and HCl levels were also predicted to peak at 10 km (6 mi) downwind at levels of about 0.66 ppm and 0.51 ppm, respectively. Aluminum oxide particulates were predicted to peak at about 405 $\mu g/m^3$ at the same distance downwind. Because the predicted peak levels would last no more than a few minutes, the predicted highest mean 1-hour concentrations are good indicators of potential hazard to the public. These predicted levels and distances downwind of LC-17 are found in Table 4-4, along with relevant Emergency Response Planning Guidelines (ERPG) developed by the American Industrial Hygiene Association. Each of the predicted highest mean 60 minute concentrations is well below these guidelines.

For a near-pad accident, in which the solid rocket fuel would largely burn, Al_2O_3 particulates were predicted to peak at about 613 µg/m^3 about 15 km (9.3 mi) downwind (see Table 4-4). Carbon monoxide and HCl were predicted to peak 24 km (15 mi) downwind at levels of 0.28 ppm and 0.12 ppm, respectively (NASA 1998a). The predicted highest mean 60-minute concentrations and distances where these concentrations occur downwind of LC-17 are found in Table 4-4. As with the on-pad accident, the highest mean 60-minute concentration predicted for each of the combustion products was well below the ERPG guidelines. Although particulates would be deposited from the explosion cloud as it was carried downwind, little wet deposition of HCl is expected unless rain falls through the explosion cloud.

On January 17, 1997 a Delta II 7925 launch vehicle failed when one of the GEMs failed structurally 7.2 seconds after liftoff from LC-17. The vehicle was destroyed, preventing hazard to the public. The vast bulk of the plume that resulted occurred over the Atlantic Ocean, with localized maximum concentrations of HCl and NO_2 at levels of 1 and 2 ppm, respectively. The impact area was beyond Cape Canaveral, as it occurred offshore over the Atlantic Ocean (Berlinrut 1997) with a high-altitude, buoyant plume extending over large parts of Brevard and Indian River counties. CCAS now has a Brevard County Emergency Management Center representative at the launch console with direct audio and video communications links to the Center beginning two hours before launch.

Large pieces of unburned solid rocket propellant may enter the Atlantic Ocean or possibly nearby surface water bodies such as the Banana River. Ammonium perchlorate in the unburned propellant would dissolve slowly into the water column creating toxic levels of perchlorate near the piece of propellant. Some mortality to aquatic life in that area would be expected until fully dissolved.

<u>VAFB</u>. <u>Liquid Propellant Spill</u>. See discussion under liquid propellant spill for CCAS.

<u>Launch Failures</u>. At VAFB, a potential accident was evaluated that could involve destruction of the GEMs and the core vehicle, resulting in ground-level burning of solid rocket fuel fragments and RP-1 from the first stage. Transport of the resulting combustion products was modeled by the U.S. Air Force under a no wind shear meteorological profile. The predicted peak concentration of Al_2O_3 particulates was 45,400 µg/m^3 at a distance of 13 km (8 mi) from SLC-2. Carbon monoxide and HCl were predicted to peak 11 km (7 mi) from SLC-2 at levels of 0.78 ppm and 0.34 ppm, respectively (NASA 1998a). The predicted highest mean 1-hour concentrations of particulates and HCl and distances downwind from SLC-2 in comparison to ERPGs are provided in Table 4-5. The predicted highest mean 1-hour concentrations of combustion products are well below ERPGs. Al_2O_3 particulates would be deposited as

TABLE 4-4. PREDICTED PEAK AND 60-MINUTE MEAN CONCENTRATIONS FOR DELTA II 7925 ACCIDENTS AT CCAS

Exhaust Cloud Constituent	Peak Concentration in ppm except where noted	Maximum 60-Minute Concentration Mean in ppm except where noted	Distance From LC-17 at which Peak/Mean Concentrations Occur in km (mi)	ERPG[a] ppm except where noted		
				1	2	3
Burning Solid Propellants						
Aluminum oxide (Al_2O_3)[b]	613 µg/m^3	85 µg/m^3	15/23 (9/14)	15,000 µg/m^3	15,000 µg/m^3	25,000 µg/m^3
Carbon monoxide (CO)	0.279	0.084	24/31 (15/19)	NA[c]		
Hydrogen chloride (HCl)	0.120	0.036	24/31 (15/19)	3	20	100
Chlorine (Cl)	0.019	0.006	24/31 (15/19)	NA		
Burning Hypergols						
Carbon monoxide (CO)	8.701	0.255	10/12 (6/7)	NA		
Nitrogen dioxide (NO_2)	0.660	0.019	10/12 (6/7)	NA		
Hydrogen chloride (HCl)	0.511	0.015	10/12 (6/7)	3	20	100
Aluminum oxide (Al_2O_3)[c]	405 µg/m^3	12 µg/m^3	10/12 (6/7)	15,000 µg/m^3	15,000 µg/m^3	25,000 µg/m^3
Ammonia (NH_3)	0.260	0.008	10/12 (6/7)	25	200	1000
Unsymmetrical dimethylhydrazine (UDMH)	0.044	0.001	10/12 (6/7)	0.03	8	80
Hydrazine (N_2H_4)	0.016	NF[d]	10/- (6 /-)	0.03	8	80
Nitric Acid (HNO_3)	0.002	NF[d]	14/- (9/-)	4	10	100

Source: NASA 1998a

a. ERPGs (Emergency Response Planning Guidelines) are developed by the American Industrial Hygiene Association. They represent the maximum airborne concentration below which it is believed nearly all individuals could be exposed for up to one hour without: (1) experiencing adverse health effects (ERPG-1); (2) perceiving clearly defined objectionable odor (ERPG-2); or (3) experiencing or developing life-threatening health effects (ERPG).
b. Al_2O_3 concentrations are given in µg/m^3 because the aluminum oxide is a solid rather than a gas.
c. NA = Not applicable or no standard.
d. NF = Not found in modeling.

TABLE 4-5. PEAK CONCENTRATIONS AND 60-MINUTE MEAN PREDICTIONS FOR LAUNCH ABORT EMISSIONS AT VAFB USING DELTA II 7925

Exhaust Cloud Constituent	Peak Concentration in ppm except where noted	Maximum 60-Minute Concentration Mean in ppm except where noted	Distance at which Peak/Mean Concentrations Occur in km (mi)	ERPG[a] ppm except where noted		
				1	2	3
Aluminum oxide (Al_2O_3)[b]	45,400 µg/m^3	6,160 µg/m^3	13/13 (8/8)	15,000 µg/m^3	15,000 µg/m^3	25,000 µg/m^3
Carbon monoxide (CO)	0.78	0.30	11/14 (7/9)	NA[c]		
Hydrogen chloride (HCl)	0.34	0.13	11/14 (7/9)	3	20	100

Source: NASA 1998a

a. ERPGs (Emergency Response Planning Guidelines) are developed by the American Industrial Hygiene Association. Represent the maximum airborne concentration below which it is believed nearly all individuals could be exposed for up to one hour without: (a) experiencing adverse health effects (ERPG-1); (b) perceiving clearly defined objectionable odor (ERPG-2); or (c) experiencing or developing life-threatening health effects (ERPG-3).

b. Al_2O_3 concentrations are given in µg/m^3 because the aluminum oxide is a solid rather than a gas.

c. NA = not applicable or no standard available.

the explosion cloud moved downwind, but no appreciable adverse effects would be expected. Wet deposition of HCl would occur in the immediate vicinity of the launch pad, but little HCl deposition would be expected downwind unless rain passes through the explosion cloud. Some uncombusted propellants could enter nearby surface waters, including the ocean (NASA 1998a). Depending upon the amounts of hydrazine and/or N_2O_4 entering the water body, adverse short-term impacts to aquatic biota could occur, including mortality in the immediate area of the propellants.

If an accident were to occur over the ocean, the potential exists for large pieces of the solid rocket propellant to enter the ocean. Solid rocket propellant (ammonium perchlorate) would dissolve slowly and would pose no threat to aquatic biota, except in the immediate vicinity of the GEMs.

Ocean systems could be temporarily impacted. However, due to the high buffering capacity of the ocean waters, rapid recovery should occur and no long-term adverse impacts would be anticipated.

4.1.4 Radiological Accident Assessment

NASA and U.S. DOE, and its contractors have conducted extensive safety assessments of launching and operating spacecraft using RHUs, e.g., the Galileo mission in 1989, the Mars Pathfinder mission in 1996, and the Cassini mission in 1997. NASA and U.S. DOE, therefore, have built upon an extensive experience base that involves:

- testing the RHUs under simulated launch accident environments;
- evaluating the effects of rapidly burning solid propellants under test or accident conditions; evaluating the probability of launch-related accidents based on evaluation of launch histories including extensive studies of the January 1997 Delta II accident at CCAS and system designs; and
- estimating the outcomes of the RHU and minor radioactive source responses to the launch accident environments.

The risk assessment for the MS 01 mission (USDOE 1999) began with identification of initial launch vehicle system failures (accident initiating conditions) and the subsequent chain of accident events that could lead to the conditions (called accident environments, e.g., fire, fragments, explosive overpressures) that could threaten the RHUs and minor radioactive sources on board the MS 01 spacecraft. An accident initiating condition is defined as the first launch vehicle system-level indication or problem (e.g., a main engine loss of thrust) that could potentially result in an accident. Based on Delta II 7425 system reliabilities and failure probabilities, a total of 12 accident initiating conditions that could lead to catastrophic failure of the launch vehicle were identified across all four major mission phases (Phase 0 Pre-Launch; Phase 1 Launch; Phase 2 Pre-Orbit/Orbit; and Phase 3 Earth Escape).

Using the twelve accident initiating conditions, U.S. DOE developed five composite accident scenarios that could potentially lead to a release of radioactive material across the four mission phases. The Jet Propulsion Laboratory (JPL) evaluated the accident scenarios and provided information on the nature and severity of the accident environments that could potentially threaten the RHUs and minor radioactive sources.

Using the accident environment information provided by JPL, U.S. DOE then determined the response of the RHUs and minor radioactive sources to the accident environments associated with each composite accident scenario within each mission phase. U.S. DOE utilized the results of modeling and data from its RHU testing and analyses during the early 1980's in support of the Galileo mission and the mid 1990's in support of the Cassini mission to determine the response of the RHUs to the accident environments. If the accident environments were severe enough compared to RHU test data and modeling, a release of radioactive material from a RHU could potentially occur. This release is called a source term. The response of the RHUs and minor radioactive sources on board the MS 01 lander/rover spacecraft to each accident environment was described in part by the estimated source term (measured in becquerels (Bq) or curies (Ci)), the particle size distribution of the material released, and the location of the release, as well as by the probability that the accident environment would cause a release (i.e., the conditional probability). The product of the composite scenario probability and the conditional probability is the total probability that a release of radioactive material could occur in a given accident scenario. The source terms for each composite accident scenario within each mission phase were then evaluated to determine the consequences of the release to the environment and to people.

The approach used was quite similar to that used in the Galileo, Pathfinder and Cassini risk assessments. Each source term was evaluated to determine how it would potentially transport and disperse from the point of release, including the effects of weather, deposition and resuspension. Long-term exposure from inhalation of resuspended material and ingestion of foodstuffs was considered, as well as the more immediate airborne and ground-based exposures that could potentially occur at the time of an accident. Approximately 10 to 20 percent of the exposure would occur during the initial passage of the airborne plume, with most of the remaining exposure occurring during the first year following the accident. Exposures after the first year would be a small fraction of the total. The consequences reported consist of overall radiological effects of the source term via all of the pathways (immediate or short-term exposure, plus subsequent exposures) and were expressed in terms of radiological dose (sievert (rem)), potential health effects to the exposed population (total detriment including excess cancer fatalities) and the area of land potentially contaminated at and above screening levels that have been used by government agencies for remedial and regulatory activities, and other purposes.

The final element of the assessment was the combination of the preceeding steps into an estimate of radiological risk associated with each composite accident scenario, each launch phase, and for the mission as a whole.

4.1.4.1 Accident Scenarios and Probabilities

This section describes potential Delta II 7425 launch vehicle accident scenarios that could occur during launch of the MS 01 lander/rover spacecraft, and summarizes the probabilities and associated accident environments. Information related to accident environments (explosion overpressure, burning liquid- and solid-propellant fires, fragments, impact on structures and ground surfaces, and reentry into Earth's atmosphere) was based on data from the Jet Propulsion Laboratory (JPL). Details of the development of the accident scenarios, probabilities, and environments are presented in USDOE 1999 and are summarized below.

<u>Accident Overview</u>. For the purpose of the U.S. DOE risk assessment, launch of the MS 01 mission's lander/rover spacecraft from CCAS was divided into four mission phases on the basis of the mission elapsed time (i.e., the time (T) relative to launch with launch initiated at T = 0 seconds) as follows:

- Phase 0 (Pre-launch, T less than 0 seconds)
- Phase 1 (Launch, from T = 0 seconds when the rocket motors are ignited to T = 270 seconds)
- Phase 2 (Pre-Orbit/Orbit, from T = 270 seconds to 1596 seconds)
- Phase 3 (from 1596 seconds to escape from Earth orbit)

The mission phases correspond to major milestones in the Delta II 7425 launch of the MS 01 lander/rover spacecraft. A total of 36 Delta II systems and subsystems and their associated reliability data and failure probabilities were evaluated. Twelve accident initiating conditions were identified as being capable of leading to a catastrophic failure of the launch vehicle. Each of the twelve accident initiating conditions was then evaluated with respect to when it could occur (see Table 4-6). This is important to the risk assessment because certain types of accident initiating conditions could be important contributors only during certain time phases in the launch. For example, accident conditions related to operation of the liquid-fueled first stage of the Delta II would be a contributor only during the first 270 seconds of the flight. At that point in time the first stage has completed burning all its fuel and the potential for malfunctions ends.

The accident initiating conditions that could occur within each launch phase were then utilized to describe one or more of five composite accident scenarios. The accident initiating conditions describing a given composite accident scenario share similar characteristics such as location (e.g., near the launch pad; at altitude), impact velocity range, and potential for dispersion of launch vehicle and spacecraft components and

TABLE 4-6. DELTA II 7425 ACCIDENT INITIATING CONDITIONS AND PROBABILITIES

Phase	Accident Initiating Conditions	Probability
Phase 0 (Pre-Launch)	Graphite epoxy motor (GEM) premature ignition	1.00×10^{-6}
T < 0 seconds	Explosion during liquid fuel loading	1.00×10^{-6}
	Structural damage	1.00×10^{-6}
Phase 1 (Launch)	Main engine explosion	3.03×10^{-3}
T = 0 to 270	Main engine loss of control	4.81×10^{-4}
seconds	Main engine loss of thrust after GEM ignition	3.03×10^{-3}
	GEM burn through or explosion	8.82×10^{-3}
	GEM(s) fail to ignite	8.80×10^{-5}
	Structural failure	1.11×10^{-4}
	Premature/inadvertent activation of Command Destruct System	3.40×10^{-5}
Phase 2 (Pre-Orbit/Orbit) T = 270 to 1596 seconds	Second Stage failure	2.38×10^{-3}
Phase 3 (Escape) T > 1596 seconds	Third Stage (PAM–D/STAR 48B upper stage) failure	5.14×10^{-3}

Source: USDOE 1999

the radioactive materials on board. The composite accident scenarios considered in the analysis include:

- On-Pad Fire/Explosion
- Aerodynamic Breakup/Command Destruct System (CDS)
- Full Stack Intact Impact
- Sub-Orbital Reentry
- Orbital-Decay/Prompt Reentry

The overall probability of each composite accident scenario was developed by summing the probabilities of each appropriate accident initiating condition provided in Table 4-6 within each composite accident scenario (see Table 4-7).

Phase 0 (Pre-Launch). Phase 0 (Pre-Launch) includes activities that could occur after the installation of the spacecraft on the Delta II 7425 launch vehicle, but before the launch command is given. Possible accident initiating conditions that could occur include premature operation of a GEM, explosion during liquid propellant loading of the Delta II 7425 (first or second stage), or structural damage to the launch vehicle (see Table 4-6). Each pre-launch accident initiating condition, if it were to occur within Phase 0, would lead to the On-Pad Fire/ Explosion composite accident scenario. Each accident initiating condition potentially occurring in Phase 0 has an estimated probability of 1×10^{-6} (1 in 1 million), and thus the probability associated with the

TABLE 4-7. DELTA II 7425 COMPOSITE ACCIDENT SCENARIOS AND PROBABILITIES

Mission Phase	Composite Accident Scenario	Accident Scenario Probability				
		Pre-Launch T < 0 seconds	Liftoff T 0 to 5 seconds	Early Launch T 5 to 38 seconds	Late Launch T 38 to 270 seconds	Pre-Orbit/Orbit and Escape T>270 seconds
Phase 0 (Pre-Launch)	On-Pad Fire/Explosion	3.00×10^{-6}	—	—	—	—
Phase 1 (Launch)	On-Pad Fire/Explosion	—	2.21×10^{-3}	—	—	—
	Aerodynamic Breakup/Command Destruct System	—	1.44×10^{-4}	5.18×10^{-3}	8.04×10^{-3}	—
	Full Stack Intact Impact	—	6.13×10^{-6}	3.90×10^{-7}	2.74×10^{-6}	—
Phase 1 Combined	1.56×10^{-2}					
Phase 2 (Pre-Orbit/Orbit)	Sub-Orbital Reentry	—	—	—	—	2.38×10^{-3}
Phase 3 (Escape)	Orbital Decay/Prompt Reentry	—	—	—	—	5.14×10^{-3}
Total Mission	2.31×10^{-2}					

Source: USDOE 1999

On-Pad Fire/Explosion composite accident scenario is the sum of the probabilities of the three accident initiating conditions, or 3.00×10^{-6} (1 in 333,000) (see Table 4-6).

Phase 1 (Launch). Phase 1 (Launch) begins at T = 0 seconds with the ignition of four GEMs and the liquid-fueled main engine. These four GEMs would deplete their fuel loads and be jettisoned from the launch vehicle at T = 67 seconds. Phase 1 ends at 270 seconds with main engine cut-off. There are seven accident initiating conditions that could occur during Phase 1 (see Table 4-6).

The accident progression within Phase 1 would depend on the time within the Phase at which an accident initiating condition occurred. Thus, Phase 1 was further divided into three time segments: Liftoff (T = 0 to 5 seconds), Early Launch (T = 5 to 38 seconds), and Late Launch (T = 38 to 270 seconds). Because the accident initiating conditions could occur within different time segments of Phase 1 the associated probabilities were also apportioned among the appropriate time segments (see Table 4-7).

During the Phase 1 - Liftoff time segment (T = 0 to 5 seconds), an explosion of the main engine, burn-through or explosion of a GEM, structural failure of the launch vehicle, a premature/inadvertent activation of the Command Destruct System or a main engine loss of control resulting in impact of the vehicle on the Fixed Umbilical Tower would lead to an On-Pad Fire/Explosion. The probability of this composite accident scenario developing in the Liftoff time segment was estimated at 2.21×10^{-3} (1 in 453). The Full Stack Intact Impact composite accident scenario could result from a main engine nozzle hard over after ignition, a main engine loss of control, a main engine loss of thrust, or a GEM failure to ignite. In addition a GEM failure to ignite or a main engine loss of thrust coupled with a failure of the Command Destruct System to cause breakup of the vehicle could also lead to a Full Stack Intact Impact scenario. The probability of this composite accident scenario developing during the Liftoff time segment was estimated at 6.13×10^{-6} (1 in 163,000).

A single GEM that fails to ignite or a loss of main engine thrust during the Liftoff time segment could still allow the launch vehicle to lift off and fly at reduced performance using thrust of the other ignited motors. After sufficient time (nominally T greater than 8 seconds), the Command Destruct System could be activated by Range Safety in response to these launch vehicle anomalies. Thus, if Range Safety, in response to the onset of either accident initiating condition during the Liftoff time segment, was to activate the Command Destruct System after T = 8 seconds, an Aerodynamic Breakup/Command Destruct System composite accident scenario would occur at a probability estimated at 1.44×10^{-4} (1 in 6,940).

During the Phase 1 - Early Launch time segment (T = 5 to 38 seconds), an explosion of the main engine, burn-through or explosion of a GEM, structural failure of the launch vehicle, or a premature/inadvertent activation of the Command Destruct System by Range Safety could lead to the Aerodynamic Breakup/Command Destruct System composite accident scenario. In the event of either a main engine loss of control or main engine loss of thrust, the Command Destruct System could be activated destroying the vehicle, also resulting in an Aerodynamic Breakup/Command Destruct System scenario. The probability of this scenario occurring during the Early Launch time segment was estimated at 5.18×10^{-3} (1 in 193).

Should the Command Destruct System fail in responding to a main engine loss of control or a main engine loss of thrust and aerodynamic stresses on the launch vehicle be insufficient to break it up, a Full Stack Intact Impact could result at an estimated probability of 3.90×10^{-7} (1 in 2.56 million). Before 38 seconds a Full Stack Intact Impact could result in impact of the launch vehicle and the lander/rover spacecraft on land surfaces. After 38 seconds, the impact would be on water (the Atlantic Ocean).

In preparing the U.S. DOE risk assessment (USDOE 1999), the January 17, 1997 Delta II 7925 accident was studied intensively. Both the STAR 48 powered upper stage and the satellite impacted as a unit about 183 m (600 ft) from the launch pad along the launch vehicle's nominal ground track. Evaluation of that accident indicated that a similar event could potentially occur during the On Pad Fire/Explosion composite accident scenario of Phase 0 (Pre-Launch) and the Liftoff time segment (T = 0 to 5 seconds) of Phase 1 (Launch), and during the Aerodynamic Breakup/Command Destruct System composite accident scenario of the Liftoff time segment and Early Launch time segment (T = 5 to 38 seconds) of Phase 1. The resulting impact could lead to mechanical damage to the RHU aeroshells, depending on the orientation at impact, and subsequent exposure to burning STAR 48B upper stage solid propellant. This in turn could potentially lead to a release of radioactive materials.

During the Phase 1 - Late Launch time segment (T = 38 to 270 seconds), the accident initiating conditions leading to either an Aerodynamic Breakup/Command Destruct System or a Full Stack Intact Impact composite accident scenario would be similar to Early Launch, except that any Full Stack Intact Impact composite accident scenario would result in water impact (i.e., the launch vehicle is over the Atlantic Ocean after T = 38 seconds). The probability of an Aerodynamic Breakup/Command Destruct System composite accident scenario was estimated at 8.04×10^{-3} (1 in 124), while the probability of a Full Stack Intact Impact composite accident scenario was estimated at 2.74×10^{-6} (1 in 365,000).

The total probability of an accident occurring within Phase 1 was estimated to be 1.56×10^{-2} (1 in 64).

Phase 2 (Pre-Orbit/Orbit). Accident initiating conditions that could potentially occur during Phase 2 (T = 270 to 1596 seconds) include failure of the first or second stage of the Delta II 7425 to separate, failure of the liquid propellant second stage engine to ignite, loss of second stage thrust or attitude control, or a failure of the payload fairing (subjecting the lander/rover spacecraft and upper stage to aerodynamic stresses). These conditions prior to T = 680 seconds, when parking orbit is attained, could lead to a Sub-Orbital Reentry composite accident scenario. A failure of the Command Destruct System could result in the intact impact of the second stage configuration (with the PAM–D/STAR 48B upper stage and spacecraft) on water, if aerodynamic/structural loading were insufficient to break apart the launch vehicle. The probability of this composite accident scenario is the same as that of the accident initiating condition, 2.38×10^{-3} (1 in 420) (see Table 4-7).

Phase 3 (Escape). During Phase 3 (from T = 1596 seconds to escape from Earth orbit), a failure of the upper stage could result in a prompt (immediate) reentry into Earth's atmosphere, or a reentry following a more gradual orbital decay (i.e., Orbital Decay/Prompt Reentry composite accident scenario). A prompt (immediate) reentry could result following loss of attitude control during the upper stage burn. An orbital decay reentry could result following an on-orbit failure of the second stage to separate from the upper stage, a failure of the upper stage to ignite, or an explosion. The probability of this composite accident scenario occurring is 5.14×10^{-3} (1 in 195).

The total probability of an accident occurring during the mission was estimated to be 2.31×10^{-2} (1 in 43). This is slightly more conservative than the actual reliability demonstrated by the Delta II launch vehicle. Looking at the launch history of the Delta II since it first went into service in February 1989, there have been a total of 86 launches over the intervening period through August 1999. Of those 86 Delta II launches, 84 were successful. Of the 2 launches classified as failures, one was a failure only of the upper stage – the satellite was placed in a lower orbit than planned. Considering two failures over 86 launches yields a 97.7 percent success record.

4.1.4.2 Accident Environments

Each composite accident scenario was then characterized by the potential accident environments that could result (i.e., accident environments are the events and/or conditions that could result from the accident initiating condition and in turn threaten the integrity of the RHUs and the minor radioactive sources on board the MS 01 lander/rover spacecraft).

The potential accident environments associated with launch area composite accident scenarios within Phases 0 and 1 include blast (explosion overpressure), fragments and projectiles, thermal (burning liquid propellant and/or solid propellant), and surface impacts of the launch vehicle and/or the STAR 48B upper stage and the MS 01 spacecraft on the launch pad and structures or the area near the launch pad. While explosions and fragments are unlikely to lead to a release from the RHUs, these environments could damage the aeroshell such that the RHUs become more susceptible to other environments such as burning solid rocket propellant (USDOE 1999).

The Phase 2 and 3 composite accident scenarios could involve spacecraft liquid propellant explosion overpressures and/or fragments ejected from an explosion of either spacecraft liquid propellants or the STAR 48B upper stage. Reentry accident environments could involve a delayed reentry of the MS 01 spacecraft or a powered reentry of the spacecraft with the upper stage still attached and operating. The spacecraft could break apart with the RHUs released to impact the Earth's surface. Reentry in either case would subject the spacecraft and/or the upper stage to aerodynamic stress and reentry heating. Additional details of the accident environments can be found in USDOE 1999.

NASA and U.S. DOE evaluated the potential accident environment in which the spacecraft and its upper stage might impact the ground as a single unit. While analyzing this situation, a conceptual separation system was considered. This conceptual separation system would function to separate the MS 01 lander/rover spacecraft from the STAR 48B upper stage in case of an accident during the first 38 seconds of the launch. This could reduce the potential for the spacecraft and upper stage to impact as a unit on or near the launch site, thereby exposing the RHUs to the intense thermal environment associated with burning solid propellant from the STAR 48B. Such a separation system would use explosive devices linked to the launch vehicle Flight Termination System to effect the separation. U.S. DOE's analysis of this conceptual system yielded small reductions in the results of the risk assessment (USDOE 1999). It was determined that such a system would not be justified, given the probable reduction in launch vehicle reliability due to added components, increased hazards associated with ordnance lines and explosives, reduction in launch vehicle lift performance due to added mass, uncertain separation system performance effectiveness, and reduced probability of overall mission success (NASA 1999). Thus the nuclear risk assessment results reported in this DEIS do not reflect incorporation of a spacecraft/upper stage separation system. Details of those analyses can be found in USDOE 1999.

4.1.4.3 Potential Accident Source Terms

This section summarizes U.S. DOE's assessment of the responses of the RHUs and minor radioactive sources on board the MS 01 lander/rover spacecraft to the accident environments that could occur within each composite accident scenario (USDOE 1999). The assessment resulted in estimates of potential radiological releases from each accident scenario, as well as the probability of a release of radioactive material from the RHUs and minor radioactive sources (i.e., the conditional probability of release) for each composite accident scenario within each mission phase. In developing the potential source terms associated with each composite accident scenario, U.S. DOE compared the expected Delta II 7425 accident environments to the data developed in its safety tests and response analyses of RHUs over the almost 20-year period RHUs have been in use. This database includes explosion overpressure tests, tests with fragments and projectiles, impact testing of RHUs and bare clads onto aluminum and steel plates, exposure of RHUs to burning solid rocket propellant, and immersion testing in seawater. The response of the RHUs to these test environments provides the basis for determining the amount of radioactive material released from the RHUs when subjected to the accident environments associated with the MS 01 mission (USDOE 1999).

A comparison of expected Delta II accident environment characteristics to the RHU test data indicates that due to the protection provided by graphitic components (the aeroshell) and the platinum-30 rhodium (Pt-30Rh) clad encapsulating the PuO_2, releases from the RHUs due to purely mechanical damage, including overpressures and fragments, would be unlikely. Damage to RHUs from mechanical loading could lead to greater susceptibility of the RHUs if they are subsequently exposed to solid propellant fires. The primary release mechanism would be exposure to high-temperature burning solid propellant fuel, which could lead to clad melting and partial vaporization of the PuO_2. If the aeroshell remains intact, any vaporized PuO_2 release would be limited to that which permeates through the graphitic components of the aeroshell. Should the aeroshell be damaged or stripped, the amount of vaporized PuO_2 released could be greater (by a factor of about 100 compared to the intact aeroshell case).

Table 4-8 summarizes the expected response of the RHUs to the predicted accident environments. Releases from the RHUs would not be expected from explosions, overpressures and liquid propellant fires. Aeroshell damage would be possible under some impact conditions and potential releases are predicted if the RHUs were in close proximity to long-burning solid propellant fires.

The Cm–244 and Co–57 minor radioactive sources and their mounting fixtures used in spacecraft instrumentation have relatively low melting temperatures compared to PuO_2,

TABLE 4-8. SUMMARY OF RHU RESPONSES TO ACCIDENT ENVIRONMENTS

Accident Environment	Accident Environment Severity	RHU Response[a]
First Stage Launch Vehicle Explosion	0.4 to 1.2 MPa overpressure and 4.4 to 11.4 kPa-s impulse[b]	No release
Second Stage Launch Vehicle Explosion	0.38 to 0.69 MPa overpressure and 0.55 to 2.8 kPa-s impulse	No release
Upper Stage Motor/GEM Explosion	0.53 to 2.0 MPa overpressure and 17.0 kPa-s impulse	No release
Spacecraft Explosion	37 to 690 kPa overpressure and 0.025 to 0.41 kPa-s impulse	No release
Liquid Propellant Fire	2300 K maximum for 14 seconds[c]	No release
Solid Propellant Fire	2273 to 2667 K for up to 250 seconds	Vapor release possible
Fragment	STAR 48B: 2.8 mm thick Ti @ 200 m/s[d] Spacecraft Hydrazine Tank: 1 mm Ti @ 50 to 76 m/s	Aeroshell damage possible No release
Impact	On-Pad Fire/Explosion: < 50 m/s[e] Aerodynamic Breakup/Command Destruct System: 45 to 122 m/s[e] Full Stack Intact Impact: < 91 m/s[e] Post-reentry: 45 m/s	Aeroshell damage possible Aeroshell damage possible Aeroshell damage possible Impact release possible (probability less than 10^{-5} given reentry)
Reentry	< 11 km/s[f] @ 122 kilometers altitude	No release

Source: USDOE 1999

a. The Cm–244 and Co–57 in the science instruments would be released in liquid and solid propellant fires and during reentry.
b. A Mega Pascal (MPa) is a unit of pressure. A kilo Pascal-second (kPa-s) is a unit of impulse. One Pascal (Pa) is a unit of pressure equal to a force of one newton per meter squared. One Newton (N) is a unit of force.
c. Kelvin – unit of measurement of temperature. 1 K = –273º C.
d. millimeter = mm; Titanium = Ti; meters per sec = m/s.
e. Mechanical shock overpressure possible (e.g., 254 MPa at 100 m/s) from impact of the STAR 48B motor onto the spacecraft.
f. kilometers per second.

and thus their release as vapor in the thermal environment of Phase 0 and Phase 1 launch area accidents would be likely. Reentry conditions in Phase 2 and Phase 3 accidents would also likely lead to the release of the Cm–244 and Co–57 at high altitudes.

Up to 7.40 x10^5 Bq (20 µCi) of Cm–242 and up to 1.11 x 10^6 Bq (30µCi) of Am–241 could also be released in the same accident scenarios releasing Cm–244, but the Cm–244 release would dominate the Cm–242 and Am–241 release. Similarly, radioisotopes of plutonium other than Pu–238 would be present but their quantities would be very small.

Reentry heating conditions in the Phase 2 and 3 composite accident scenarios would not threaten the integrity of the RHUs. The RHUs have been designed to withstand the heating conditions associated with reentry from Earth orbit without release (USDOE 1988). Post-reentry impact on rock could result in a small release, however. The assessment set the potential release at 5.70 x 10^4 Bq (1.54 x 10^{-6} Ci), at a conditional probability of 1.0 x 10^{-5} (1 in 100,000). It was assumed, given the lesser degree of protection of the minor radioactive sources on board the spacecraft and the lower melting temperatures associated with the sources compared with the RHUs, on the average 50 percent of the Cm–244 and 25 percent of the Co–57 would be released during reentry.

The source term assessment evaluated the potential source terms resulting from intact RHUs, damaged RHUs, and bare clads being exposed to burning solid and liquid propellant environments and combinations of those environments within each Phase 0 and Phase 1 composite accident scenario. This assessment resulted in a distribution of potential source terms for each composite accident scenario. These distributions were then evaluated to determine the expectation (mean) and 99th percentile source terms for each scenario and the corresponding conditional probability of release. (The 99th percentile case represents levels that would be exceeded 1 percent of the time.)

The mean source terms from the RHUs (Pu–238), and the minor radioactive sources (Cm–244 and Co–57) and their probabilities are presented in Table 4-9, and the 99th percentile values are presented in Table 4-10. A summary of the total probabilities of release for each composite accident scenario is presented in Table 4-11. Essential features of the results are summarized below.

<u>Phase 0 (Pre-Launch)</u>. During the Pre-launch period (Phase 0) from RHU installation into the spacecraft (two days prior to launch) and prior to launch vehicle liftoff, on-pad accidents involving explosion of launch vehicle propellants could result in a release with a total probability of 2.44 x 10^{-6} (1 in 410,000). The expectation (mean) source terms are estimated to be 2.11 x 10^9 Bq (0.057 Ci) for Pu–238, 1.63 x 10^9 Bq (0.044 Ci) for Cm–244, and 2.89 x 10^9 Bq (0.078 Ci) for Co–57.

The 99th percentile source terms (Table 4-10) were estimated at 3.15 x 10^{10} Bq (0.852 Ci) for Pu–238, and 2.07 x 10^9 Bq (0.056 Ci) for Cm–244 and 3.26 x 10^9 Bq (0.088 Ci) for Co–57, at a total probability of 2.44 x 10^{-8} (1 in 41 million).

TABLE 4-9. SOURCE TERM SUMMARY EXPECTATION (MEAN) VALUES

Mission Phase	Accident Scenario	Accident Scenario Probability	RHU[a]		Minor Radioactive Sources[b]		
			Conditional Probability	Pu–238 Bq (Ci)	Conditional Probability	Cm–244 Bq (Ci)	Co–57 Bq (Ci)
0 (Pre-Launch, T < 0 seconds)	On-Pad Fire/Explosion	3.00×10^{-6}	0.629	2.11×10^{9} (0.057)	0.814	1.63×10^{9} (0.044)	2.89×10^{9} (0.078)
1 (Launch, T = 0 to 270 seconds)	On-Pad Fire/Explosion	2.21×10^{-3}	0.620	2.15×10^{9} (0.058)	0.810	1.59×10^{9} (0.043)	2.92×10^{9} (0.079)
1a (Lift-off, T = 0 to 5 seconds)	Aerodynamic Breakup/Command Destruct System	1.44×10^{-4}	0.627	3.18×10^{9} (0.086)	0.720	1.70×10^{9} (0.046)	3.07×10^{9} (0.083)
	Full Stack Intact Impact	6.13×10^{-6}	0.597	4.29×10^{9} (0.116)	0.798	1.59×10^{9} (0.043)	2.85×10^{9} (0.077)
1b (Early, T = 5 to 38 seconds)	Aerodynamic Breakup/Command Destruct System	5.18×10^{-3}	0.220	4.22×10^{9} (0.114)	0.240	1.74×10^{9} (0.047)	3.03×10^{9} (0.082)
	Full Stack Intact Impact	3.90×10^{-7}	0.299	4.26×10^{9} (0.115)	0.650	1.15×10^{9} (0.031)	2.07×10^{9} (0.056)
1c (Late, T = 38 to 270 seconds)	Aerodynamic Breakup/Command Destruct System	8.04×10^{-3}	—	—	—	—	—
	Full Stack Intact Impact	2.74×10^{-6}	—	—	—	—	—
Phase 1 Combined	—	1.56×10^{-2}	0.167	3.11×10^{9} (0.084)	0.202	1.67×10^{9} (0.045)	2.96×10^{9} (0.080)

TABLE 4-9. SOURCE TERM SUMMARY EXPECTATION (MEAN) VALUES (Continued)

Mission Phase	Accident Scenario	Accident Scenario Probability	RHU[a]		Minor Radioactive Sources[b]		
			Conditional Probability	Pu–238 Bq (Ci)	Conditional Probability	Cm–244 Bq (Ci)	Co–57 Bq (Ci)
2 (Pre-Orbit/Orbit, T = 270 to 1596 seconds)	Sub-Orbital Reentry	2.38×10^{-3}	$<1.00 \times 10^{-5}$	5.70×10^{4} (1.54×10^{-6})	1.00	1.85×10^{9} (0.050)	3.26×10^{9} (0.088)
3 (Earth Escape, T > 1596 seconds)	Orbital-Decay/Prompt Reentry	5.14×10^{-3}	$<1.00 \times 10^{-5}$	5.70×10^{4} (1.54×10^{-6})	1.00	1.85×10^{9} (0.050)	3.26×10^{9} (0.088)
Overall Mission	—	2.31×10^{-2}	0.113	3.11×10^{9} (0.084)	0.462	1.81×10^{9} (0.049)	3.18×10^{9} (0.086)

Source: USDOE 1999

a. Pu–238 releases in Phases 0 and 1 are due to exposure to burning solid propellants, releasing plutonium dioxide as a vapor. Releases in Phases 2 and 3 are due to post-reentry impact on rock, releasing plutonium dioxide as small particles (less than 5 micrometers in physical diameter).

b. Cm–244 and Co–57 releases in Phases 0 and 1 are due to exposure to burning liquid and solid propellants, with release as a vapor at ground level. Releases in Phases 2 and 3 are due to reentry heating, releasing Cm–244 and Co–57 as a vapor at high altitude.

TABLE 4-10. SOURCE TERM SUMMARY (99TH PERCENTILE VALUES)[a]

Mission Phase	Accident Scenario	Accident Scenario Probability	Conditional Probability[a]	RHU[b]	Minor Radioactive Sources[c]	
				Pu–238 Bq (Ci)	Cm–244 Bq (Ci)	Co–57 Bq (Ci)
0 (Pre-Launch, T < 0 seconds)	On Pad Fire/Explosion	3.00x10^{-6}	8.14x10^{-3}	3.15x10^{10} (0.852)	2.07x10^{9}. (0.056)	3.26x10^{9} (0.088)
1 (Launch, T = 0 to 270 seconds)	On-Pad Fire/Explosion	2.21x10^{-3}	8.10x10^{-3}	3.15x10^{10} (0.852)	2.07x10^{9} (0.056)	3.26x10^{9} (0.088)
1a (Lift-off, T = 0 to 5 seconds)	Aerodynamic Breakup/Command Destruct System	1.44x10^{-4}	7.20x10^{-3}	3.15x10^{10} (0.852)	2.07x10^{9} (0.056)	3.26x10^{9} (0.088)
	Full Stack Intact Impact	6.13x10^{-6}	7.98x10^{-3}	4.23x10^{10} (1.144)	2.07x10^{9} (0.056)	3.26x10^{9} (0.088)
1b (Early, T = 5 to 38 seconds)	Aerodynamic Breakup/Command Destruct System	5.18x10^{-3}	2.40x10^{-3}	4.23x10^{10} (1.144)	2.07x10^{9} (0.056)	3.26x10^{9} (0.088)
	Full Stack Intact Impact	3.90x10^{-7}	6.50x10^{-3}	4.23x10^{10} (1.144)	2.07x10^{9} (0.056)	3.26x10^{9} (0.088)
1c (Late, T = 38 to 270 seconds)	Aerodynamic Breakup/Command Destruct System	8.04x10^{-3}	—	—	—	—
	Full Stack Intact Impact	2.74x10^{-6}	—	—	—	—
Phase 1 Combined	—	1.56x10^{-2}	2.02x10^{-3}	3.58x10^{10} (0.968)	2.07x10^{9} (0.056)	3.26x10^{9} (0.088)

TABLE 4-10. SOURCE TERM SUMMARY (99TH PERCENTILE VALUES)[a] (Continued)

Mission Phase	Accident Scenario	Accident Scenario Probability	Conditional Probability[a]	RHU[b]	Minor Radioactive Sources[c]	
				Pu–238 Bq (Ci)	Cm–244 Bq (Ci)	Co–57 Bq (Ci)
2 (Pre-Orbit/Orbit, T = 270 to 1596 seconds)	Sub-Orbital Reentry	2.38×10^{-3}	1.00×10^{-2}	—	3.63×10^{9} (0.098)	6.48×10^{9} (0.175)
3 (Earth Escape, T > 1596 seconds)	Orbital-Decay/Prompt Reentry	5.14×10^{-3}	1.00×10^{-2}	—	3.63×10^{9} (0.098)	6.48×10^{9} (0.175)
Overall Mission	—	2.31×10^{-2}	4.62×10^{-3}	1.06×10^{10} (0.286)	3.18×10^{9} (0.086)	5.51×10^{9} (0.149)

Source: USDOE 1999

a. Reported as the 99th percentile source term given a Cm–244 release.

b. Pu–238 releases in Phases 0 and 1 are due to exposure to burning solid propellants, releasing plutonium dioxide as a vapor. Releases in Phases 2 and 3 are due to post-reentry impact on rock, releasing plutonium dioxide as small particles (less than 5 micrometers in physical diameter).

c. Cm–244 and Co–57 releases in Phases 0 and 1 are due to exposure to burning liquid and solid propellants, with release as a vapor at ground level. Releases in Phases 2 and 3 are due to reentry heating, with release of Cm–244 and Co–57 as a vapor at high altitude.

TABLE 4-11. PROBABILITY SUMMARY FOR EXPECTATION (MEAN) SOURCE TERMS[a]

Mission Phase	Accident Scenario	Accident Scenario Probability	Conditional Probability	Total Probability
0 (Pre-Launch, T < 0 seconds)	On-Pad Fire/Explosion	3.00×10^{-6}	0.814	2.44×10^{-6}
1 (Launch, T = 0 to 270 seconds)	On-Pad Fire/Explosion	2.21×10^{-3}	0.810	1.79×10^{-3}
1a (Lift-off, T = 0 to 5 seconds)	Aerodynamic Breakup/Command Destruct System	1.44×10^{-4}	0.720	1.04×10^{-4}
	Full Stack Intact Impact	6.13×10^{-6}	0.798	4.89×10^{-6}
1b (Early, T = 5 to 38 seconds)	Aerodynamic Breakup/Command Destruct System	5.18×10^{-3}	0.240	1.24×10^{-3}
	Full Stack Intact Impact	3.90×10^{-7}	0.650	2.53×10^{-7}
1c (Late, T = 38 to 270 seconds)	Aerodynamic Breakup/Command Destruct System	8.04×10^{-3}	—	—
	Full Stack Intact Impact	2.74×10^{-6}	—	—
Phase 1 Combined	—	1.56×10^{-2}	0.202	3.15×10^{-3}
2 (Pre-Orbit/Orbit, T = 270 to 1596 seconds)	Sub-Orbital Reentry	2.38×10^{-3}	1.000	2.38×10^{-3}
3 (Earth Escape, T > 1596 seconds)	Orbital-Decay/Prompt Reentry	5.14×10^{-3}	1.000	5.14×10^{-3}
Phase 2 and 3 Combined	—	7.52×10^{-3}	1.000	7.52×10^{-3}
Overall Mission	—	2.31×10^{-2}	0.462	1.07×10^{-2}

Source: USDOE 1999

a. The conditional and total probabilities are for the expectation (mean) source terms. The 99th percentile source terms would have conditional and total probabilities of 0.01 times those for the expectation (mean) source terms.

Phase 1 (Launch). During Phase 1 from liftoff to 38 seconds, after which land impacts in the launch area are no longer possible, initiating accidents which could result in a radioactive material release include explosions due to launch vehicle malfunctions, command destruct actions, and intact impacts. The total probability of a release would be 3.15×10^{-3} (1 in 317), with mean source terms of 3.11×10^{9} Bq (0.084 Ci) of Pu–238, 1.67×10^{9} Bq (0.045 Ci) of Cm–244, and 2.96×10^{9} Bq (0.080 Ci) of Co–57.

The 99th percentile source terms (Table 4-10) were estimated at 3.58×10^{10} Bq (0.968 Ci) for Pu–238, 2.07×10^{9} Bq (0.056 Ci) for Cm–244, and 3.26×10^{9} Bq (0.088 Ci) for Co–57 at a total probability of 3.15×10^{-5} (1 in 31,700).

Phases 2 and 3 (Pre-Orbit/Orbit and Earth Escape). Accidents in Phases 2 and 3 which occur after 270 seconds, but prior to Earth escape, would expose the RHUs and the minor radioactive sources to reentry conditions. Accidents prior to the attainment of Earth parking orbit would lead to prompt sub-orbital reentry within minutes (prompt reentry). Following spacecraft breakup during reentry, this would result in impacts of intact RHUs along the vehicle flight path over the Atlantic Ocean, southern Africa, and Madagascar.

Accidents which occur after attaining parking orbit could result in orbital decay reentry from minutes to years after the accident. Orbital decay impacts on land could occur anywhere between north and south latitude bands determined by the day and time of launch. For the most probable accident, impacts on land would occur in a band between 28º S and 28º N latitudes. As noted previously, only post-reentry ground impacts on a hard surface, such as rock, would produce a PuO_2 release, although the conditional probability would be very small (less than 10^{-5} or less than 1 in 100,000). However, all accidents in Phases 2 and 3 would lead to the high-altitude release of Cm–244 and Co–57 due to reentry heating.

Thus, for Phase 2 and Phase 3 combined, the total probability of an accident resulting in a release from the RHUs and minor radioactive sources would be 7.52×10^{-3} (1 in 133) with mean source terms of 1.85×10^{9} Bq (0.050 Ci) of Cm–244 and 3.26×10^{9} Bq (0.088 Ci) of Co–57 at high altitude. If the RHUs were to impact rock and fail, a ground level release of 5.70×10^{4} Bq (0.00000154 Ci) of Pu–238 could occur. The 99th percentile source terms were estimated as 3.63×10^{9} Bq (0.098 Ci) of Cm–244 and 6.48×10^{9} Bq (0.175 Ci) of Co–57 released at high altitude, and if the RHUs were to hit rock, again at a total probability of 7.52×10^{-5} (1 in 13,300).

Across all mission Phases and composite accident scenarios, the total probability of an accident resulting in a release from the RHUs and minor radioactive sources would be 1.07×10^{-2} (1 in 93).

4.1.5 Environmental Consequences and Risks of MS 01 Mission Radiological Accidents

The following sections discuss the methodologies and radiological consequences associated with a mission accident. Section 4.1.5.1 describes the methodologies that lead to the radiological consequences (Section 4.1.5.2). Section 4.1.5.3 describes the potential impacts to the CCAS and regional environment and to the global environment.

4.1.5.1 Radiological Consequences Methodology

The methodology used in the radiological consequence analysis is summarized below in terms of plume configurations for launch area releases, atmospheric transport and dispersion modeling, exposure pathways, internal dosimetry, and health effects models used in the assessment (USDOE 1999).

All the source terms would involve releases to the atmosphere, either near ground level or at high altitudes. The atmospheric transport and dispersion of such releases were modeled to determine the time-integrated ground and airborne concentrations with respect to the potentially affected population and surface feature (land/water) distributions and other environmental media (e.g., vegetation, soil, and water). Generally, this methodology uses two models: EMERGE and LOPAR. EMERGE is used for potential Phase 0 and Phase 1 accident releases in the troposphere (up to an altitude of about 10 km (6 mi)) out to a distance about 100 km (62 mi) from the launch pad or release point. For Phase 0 and Phase 1, releases that were modeled to disperse beyond 100 km (62 mi), the radioactive material were assumed to disperse evenly throughout the latitude band. For the purposes of U.S. DOE's risk assessment the 100-km (62-mi) distance from the launch pad or release point is called “On Grid”. Beyond that distance is called “Off Grid”. LOPAR is used for potential Phase 2 and Phase 3 vapor releases at high altitudes distributing the largest amount of vapor within the Earth's hemisphere within which the spacecraft or RHU would reenter.

- EMERGE, a three-dimensional Gaussian puff-trajectory model that treats time- and space-varying meteorological conditions, accounts for the vertical plume configuration; particle-size-dependent transport, deposition, and plume depletion; and sea-breeze recirculation in the vicinity of the launch site. The EMERGE model uses a demographic and surface feature database for the CCAS/KSC regional area.
- LOPAR, an empirical model derived for small particles from weapons testing data, accounts for worldwide circulation patterns and delayed fallout as a function of latitude band. LOPAR interfaces with a worldwide demographic database to facilitate estimating radiological impacts.

After modeling the atmospheric transport and dispersion of the potential releases with one or more of these models, the radiation doses to the potentially affected general population from exposure to the radioactive material concentrations released to the environment were determined by considering the following exposure pathways:

- direct inhalation of released material;
- inhalation of resuspended material previously deposited on the ground;

- ingestion of contaminated food (vegetables and seafood); and
- external exposure to ground-deposited material.

The exposure pathway parameters and the internal dose conversion factors used in this analysis are identical to, or updated from, those used for previous mission risk assessments (Galileo, Mars Pathfinder, and Cassini) (USDOE 1999).

Plume Configurations. The radiological consequences of low-level radioactive material releases would be influenced by the initial distribution of material in the plume and the configuration of the plume. Types of release configurations would include those associated with ground-level releases outside thermal environments and those associated with propellant explosion environments. Three plume configurations were considered: (1) the plume associated with burning of liquid and solid propellants; (2) the plume associated with burning of the STAR 48B upper stage propellants only; and (3) the plume associated with burning of the solid propellants in the GEMs and the STAR 48B upper stage.

Atmospheric Transport and Dispersion Modeling. The EMERGE model was used for launch area releases. EMERGE utilized 50 historical meteorological data sequences for each of the three vertical plume configurations identified above, with a 3.70×10^{10} Bq (1 Ci) source term. For each composite accident scenario up to T = 38 seconds, the results for 150 cases (50 data sequences and 3 plume configurations) were scaled for 17 combinations of source terms (Pu–238, Cm–244, and Co–57) and plume configurations to arrive at 850 (50 meteorological cases x 17 source term combinations) results for each composite accident scenario.

That portion of the material determined to be transported beyond the 100-km (62-mi) radius EMERGE grid was assumed to be uniformly deposited over the latitude band for subsequent analysis of global consequences. Such material would be removed from the troposphere primarily by precipitation scavenging.

Reentry heating of the RHUs and minor radioactive sources during a Phase 2 or Phase 3 composite accident scenario could result in high altitude release Cm–244 and Co–57 vapor from the minor radioactive source inventories on board the MS 01 spacecraft. The RHUs have been designed to withstand this accident environment and would not be expected to release any PuO_2. As noted earlier the LOPAR model distributes most of the vapor release (Cm–244 and Co–57) within the Earth hemisphere in which reentry would most likely occur (specifically the mid-latitude bands of the northern hemisphere), with the remainder distributed over the balance of the Earth.

Exposure Pathway Data, Parameters, and Assumptions. The demographic data for the KSC/CCAS region for the offsite residential population, spectators, and onsite workers were those from Halliburton NUS Corporation (1991), projected to the year 2001. Since the spectator data was representative of Space Shuttle launches, the number of spectators for the MS 01 mission launched by a Delta II would be expected to be less. For this analysis, the number of spectators was taken to be 10 percent of spectators estimated for a Space Shuttle launch.

The exposure pathway parameters for the inhalation, ingestion, and external dose pathway, including dose conversion factors, are the same as those used in previous risk assessments for the Galileo, Ulysses, Pathfinder, and Cassini missions. The internal dose conversion factors are based on International Commission on Radiological Protection (ICRP)-30 (ICRP 1979). The resuspension factor used in EMERGE was also the same (i.e., initially 10^{-5}/m, decreasing exponentially to 10^{-9}/m over two years, and remaining at that level thereafter). The analysis assumed a 50-year exposure period in the time integration of doses following the postulated accident.

4.1.5.2 Radiological Consequences

The radiological consequences of a given accident scenario have been calculated in terms of (1) maximum individual dose; (2) collective dose; (3) health effects; and (4) land area contaminated at or above specified levels.

Dose is the amount of ionizing radiation deposited in body tissues via the applicable exposure pathways and is expressed in international units of measurement called “sieverts”, or “rems” in the more familiar terminology in the U.S. (One sievert (Sv) is equal to 100 rem.) By way of comparison, the average individual in the United States receives an annual dose from all natural of radiation (called a normal background dose) of about 0.003 Sv per year (about 0.300 rem/yr) (see Table 4-12).

The maximum individual dose is the maximum dose that would be delivered to a single individual within each accident case simulation. Collective dose is the sum of the radiation dose received by all individuals potentially exposed to radiation from a possible release in units of “person-sievert” (“person-rem”).

Radiation can cause a variety of adverse health effects in people. A large dose of radiation can cause prompt mortality. At low doses of radiation, the most important adverse health effect for depicting the consequences of environmental and occupational radiation exposures (which are typically low doses) is the potential inducement of cancers that may lead to death in later years. This effect is referred to as excess cancer fatalities because the cancer may take years to develop and for death to occur, and may in fact never actually be the ultimate cause of death.

The potential number of health effects that could result in the exposed population by U.S. DOE using the “excess cancer fatalities” dose-to-effect factors in Table 4-13. Multiplying the collective dose estimated for each accident scenario by these factors results in the number of health effects that could result within the exposed population over a 50-year period following the accident. A factor of 0.0004 excess cancer fatalities for each person-rem of dose was applied to launch site workers and 0.0005 excess cancer fatalities per person-rem were applied to spectators and offsite

TABLE 4-12. AVERAGE ANNUAL EFFECTIVE DOSE EQUIVALENT OF IONIZING RADIATION TO A MEMBER OF THE U.S. POPULATION

Source	Effective Dose Equivalent[a]	
	Sv/yr (rem/yr)	Percent of Total
Natural		
Radon[b]	2.0×10^{-3} (0.2)	55
Cosmic	2.7×10^{-4} (0.027)	8
Terrestrial	2.8×10^{-4} (0.028)	8
Internal	3.9×10^{-4} (0.039)	11
Subtotal — Natural	3.0×10^{-3} (0.3)	82
Manmade		
Medical		
X-ray diagnosis	3.9×10^{-4} (0.039)	11
Nuclear medicine	1.4×10^{-4} (0.014)	4
Consumer products	1.0×10^{-4} (0.010)	3
Other		
Occupational	$<1.0 \times 10^{-5}$ (<0.001)	<0.03
Nuclear fuel cycle	$<1.0 \times 10^{-5}$ (<0.001)	<0.03
Fallout	$<1.0 \times 10^{-5}$ (<0.001)	<0.03
Miscellaneous[c]	$<1.0 \times 10^{-5}$ (<0.001)	<0.03
Subtotal — Manmade	6.4×10^{-4} (0.064)	18
Total Natural and Manmade[d]	3.64×10^{-3} (0.364)	100

Source: National Research Council 1990

a. Effective dose equivalent is proportional to incremental risk in cancer.
b. Dose equivalent to bronchi from radon decay products. The assumed weighting factor for the effective dose equivalent relative to whole-body exposure is 0.08.
c. Department of Energy facilities, smelters, transportation, etc.
d. The 50-year effective dose commitment is 50 yr x 3.64×10^{-3} Sv/yr (3.64×10^{-1} rem/yr) or 1.82×10^{-1} Sv (1.82×10^{1} rem).

TABLE 4-13. RISK OF EXCESS CANCER FATALITIES AND OTHER HEALTH EFFECTS FROM EXPOSURE TO 1 PERSON-REM OF RADIATION

Population[a]	Excess Cancer Fatalities	Nonfatal Cancer	Genetic Effects	Total Detriment
Workers	0.0004	0.00008	0.00008	0.00056
Public	0.0005	0.0001	0.00013	0.00073

Source: ICRP 1991

a. The difference between worker risk and the general public risk is attributable to the fact that the general population includes individuals in sensitive age groups (that is, less than 18 years, or more than 65 years).

population. (The factors expressed in international units would be 0.000004 per person-sievert for launch site workers, and 0.000005 per person-sievert for spectators and offsite populations.) In addition to excess cancer fatalities, other effects could result from environmental and occupational exposures to radiation. These effects include nonfatal cancers among the exposed population and the genetic effects in subsequent generations. Table 4-13 shows the dose-to-effect factors for these potential effects as well as the excess cancer fatalities, as determined by the ICRP (ICRP 1991). The combined effect of fatal cancers, nonfatal cancers, and genetic effects is called total detriment (see Table 4-13). The total detriment risks in Table 4-13 thus reflect the sum of all of the risks from these potential outcomes. For more details regarding detriment and associated estimates for the MS 01 mission, see USDOE 1999.

Summaries of the radiological consequences by mission phase are provided in Tables 4-14, 4-15 and 4-16 for maximum individual dose, collective dose, and health effects, respectively. For Phases 0 and 1 accidents, the relative percent contributions to the radiological consequences from Pu–238, Cm–244, and Co–57, both on-grid (<100 km (<62 mi)) and off-grid (>100 km (>62 mi)), are presented in Table 4-17. Within 100 km (62 mi) of the initial release (on-grid), the models take site-specific dispersion meteorology into account. Beyond 100 km (62 mi) of the initial release (off-grid), the models assume a uniform tropospheric concentration of airborne radioactive material within the CCAS latitude band of the worldwide database. Results for each mission phase and composite accident scenario are provided for the expectation (mean) source terms and the 99th percentile source terms.

TABLE 4-14. RADIOLOGICAL CONSEQUENCES: MAXIMUM INDIVIDUAL DOSE[a,b]

Mission Phase	Accident Scenario	Mean Sv (rem)	99th Percentile Sv (rem)
0 (Pre-Launch)	On-Pad Fire/Explosion	9.24×10^{-5} (9.24×10^{-3})	2.47×10^{-3} (2.47×10^{-1})
1 (Launch) 1a (Liftoff)	On-Pad Fire/Explosion	9.18×10^{-5} (9.18×10^{-3})	2.47×10^{-3} (2.47×10^{-1})
	Aerodynamic Breakup/Command Destruct System	3.03×10^{-4} (3.03×10^{-2})	9.45×10^{-3} (9.45×10^{-1})
	Full Stack Intact Impact	1.04×10^{-4} (1.04×10^{-2})	2.51×10^{-3} (2.51×10^{-1})
1b (Early)	Aerodynamic Breakup/Command Destruct System	4.51×10^{-4} (4.51×10^{-2})	1.19×10^{-2} (1.19×10^{0})
	Full Stack Intact Impact	6.77×10^{-5} (6.77×10^{-3})	2.47×10^{-3} (2.47×10^{-1})
1c (Late)	Aerodynamic Breakup/Command Destruct System	—	—
	Full Stack Intact Impact	—	—
Phase 1 Combined	—	2.41×10^{-4} (2.41×10^{-2})	9.45×10^{-3} (9.45×10^{-1})
2 (Pre-Orbit/Orbit)	Sub-Orbital Reentry	4.16×10^{-8} (4.16×10^{-6})	1.22×10^{-7} (1.22×10^{-5})
3 (Earth Escape)	Orbital-Decay/Prompt Reentry	4.16×10^{-8} (4.16×10^{-6})	1.22×10^{-7} (1.22×10^{-5})
Overall Mission	—	7.09×10^{-5} (7.09×10^{-3})	2.78×10^{-3} (2.78×10^{-1})

Source: USDOE 1999

a. Results do not take any credit for intervention or clean-up.
b. Reported for a 50-year exposure period.

TABLE 4-15. RADIOLOGICAL CONSEQUENCES: COLLECTIVE DOSE[a,b]

Mission Phase	Accident Scenario	Mean person-Sv (person-rem)	99th Percentile person-Sv (person-rem)
0 (Pre-Launch)	On-Pad Fire/Explosion	1.57×10^{-1} (1.57×10^{1})	1.93×10^{0} (1.93×10^{2})
1 (Launch) 1a (Liftoff)	On-Pad Fire/Explosion	1.56×10^{-1} (1.56×10^{1})	1.93×10^{0} (1.93×10^{2})
	Aerodynamic Breakup/Command Destruct System	4.09×10^{-1} (4.09×10^{1})	5.15×10^{0} (5.15×10^{2})
	Full Stack Intact Impact	2.41×10^{-1} (2.41×10^{1})	2.70×10^{0} (2.70×10^{2})
1b (Early)	Aerodynamic Breakup/Command Destruct System	6.38×10^{-1} (6.38×10^{1})	8.18×10^{0} (8.18×10^{2})
	Full Stack Intact Impact	1.53×10^{-1} (1.53×10^{1})	2.46×10^{0} (2.46×10^{2})
1c (Late)	Aerodynamic Breakup/Command Destruct System	—	—
	Full Stack Intact Impact	—	—
Phase 1 Combined	—	3.56×10^{-1} (3.56×10^{1})	5.02×10^{0} (5.02×10^{2})
2 (Pre-Orbit/Orbit)	Sub-Orbital Reentry	5.04×10^{-2} (5.04×10^{0})	1.45×10^{-1} (1.45×10^{1})
3 (Earth Escape)	Orbital-Decay/Prompt Reentry	5.04×10^{-2} (5.04×10^{0})	1.45×10^{-1} (1.45×10^{1})
Overall Mission	—	1.40×10^{-1} (1.40×10^{1})	1.58×10^{0} (1.58×10^{2})

Source: USDOE 1999

a. Results do not take any credit for intervention or clean-up.
b. Reported for a 50-year exposure period.

TABLE 4-16. RADIOLOGICAL CONSEQUENCES: HEALTH EFFECTS[a,b]

Mission Phase	Accident Scenario	Mean	99^{th} Percentile
0 (Pre-Launch)	On-Pad Fire/Explosion	7.78×10^{-3}	9.54×10^{-2}
1 (Launch)			
1a (Liftoff)	On-Pad Fire/Explosion	7.74×10^{-3}	9.51×10^{-2}
	Aerodynamic Breakup/Command Destruct System		
		2.02×10^{-2}	2.58×10^{-1}
	Full Stack Intact Impact		
		1.20×10^{-2}	1.35×10^{-1}
1b (Early)	Aerodynamic Breakup/Command Destruct System		
	Full Stack Intact Impact	3.16×10^{-2}	4.08×10^{-1}
	Aerodynamic Breakup/Command Destruct System	7.58×10^{-3}	1.22×10^{-1}
1c (Late)			
	Full Stack Intact Impact		
		—	—
	—		
		—	—
Phase 1 Combined		1.75×10^{-2}	2.51×10^{-1}
2 (Pre-Orbit/Orbit)	Sub-Orbital Reentry	2.52×10^{-3}	7.25×10^{-3}
3 (Earth Escape)	Orbital-Decay/Prompt Reentry	2.52×10^{-3}	7.25×10^{-3}
Overall Mission	—	6.92×10^{-3}	7.89×10^{-2}

Source: USDOE 1999

a. Results do not take any credit for intervention or clean-up.
b. Reported for a 50-year exposure period. Based on ICRP-60 health effects estimators of 4×10^{-2} health effects per person-Sv (4×10^{-4} health effects per person-rem) for workers and 5×10^{-2} health effects per person-Sv (5×10^{-4} health effects per person-rem) for the general population (spectators and residents, both on-grid and off-grid).

TABLE 4-17. RELATIVE PERCENT CONTRIBUTIONS TO RADIOLOGICAL CONSEQUENCES (PHASES 0 AND 1)[a]

Result Type	Pu–238	Cm–244	Co–57
Mean Values			
On-Grid (<100 km (<62 mi))	46.7	22.4	0.011
Off-Grid (>100 km (>62 mi))	21.2	9.7	0.045
Total Percent Contribution	67.9	32.1	0.056
99th Percentile Values			
On-Grid (<100 km (<62 mi))	77.9	4.5	0.002
Off-Grid (>100 km (>62 mi))	16.9	0.7	0.003
Total Percent Contribution	94.8	5.2	0.005

Source: USDOE 1999

a. Relative contributions to collective dose and health effects in Phases 0 and 1 accidents. In Phases 2 and 3, the collective dose and health effects would largely be due to Cm–244 released at high altitude.

Essential features of the results are summarized below.

- Phase 0 (Pre-launch). The mean and 99th percentile maximum individual doses (Table 4-14) estimated for a Phase 0 accident would be a fraction of a sievert. The mean maximum individual dose (9.24×10^{-5} Sv; 9.24×10^{-3} rem) estimated is a committed dose over a 50-year period with 10 to 20 percent occurring with plume passage, and 80 to 90 percent occurring thereafter. For comparative purposes, the mean dose would be about 3 percent of the annual average dose to a person living in the U.S., from natural background radiation (see Table 4-12). The 99th percentile dose (i.e., the dose that would be exceeded 1 percent of the time) would be about 82 percent of the annual natural background dose. Natural background radiation over a 50-year period would amount to about 150 Sv (15 rem) on the average.

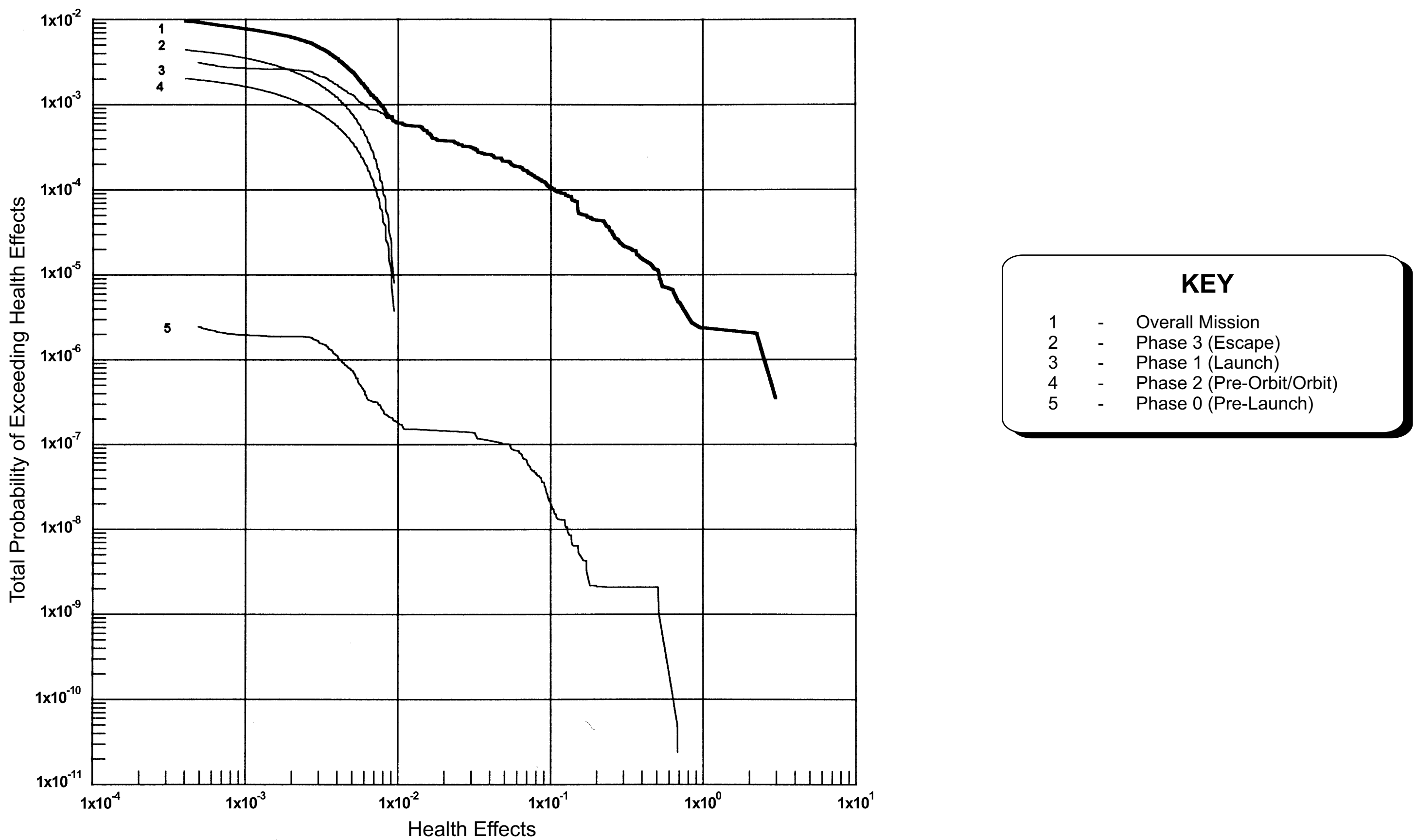
  Both the mean and 99th percentile collective doses to the potentially exposed population would be very small (see Table 4-15) and have been estimated to result in a fraction of a health effect (excess cancer fatality) in the exposed population.

- Phase 1 (Launch). As with Phase 0, the expectation (mean) and 99th percentile assessment yielded maximum individual doses that would be a small fraction of a sievert for the mean source terms, and still a fraction of a sievert for the 99th percentile source terms (see Table 4-14). The highest mean maximum individual dose (4.51×10^{-4} Sv; 4.51×10^{-2} rem) that was estimated for a Phase 1b accident would be the equivalent of about 15 percent of the annual background dose or approximately equivalent to a medical x-ray (see Table 4-12). The 99^{th} percentile maximum individual dose for a Phase 1 b accident (1.19×10^{-2} Sv; 1.19 rem) would be about four times the average annual natural background dose. The 99^{th} percentile maximum individual dose, would be well below (about 25 percent) the U.S. EPA guidance level. The collective doses estimated for the mean and 99^{th} percentile (Table 4-15) were small relative to the potentially exposed population resulting in a fraction of a excess cancer fatality in estimated health effects (see Table 4-16). The relative contributions of Pu–238, Cm–244, and Co–57 to the mean radiological consequences in Phase 0 and Phase 1 would be about 67.9, 32.1, and 0.056 percent, respectively.

- Phases 2 and 3 (Pre-Orbit/Orbit and Escape). Maximum individual doses would be a very small fraction of a sievert; the collective dose to the potentially exposed population would also be very small, resulting in a small fraction of a excess cancer fatality in all analyses. The maximum individual doses in Phases 2 and 3 would be due to Pu–238 released at ground-level, while the collective dose and health effects would be due primarily to Co–57 and Cm–244 released as a vapor at high altitude.

Figure 4-1 graphically depicts the health effects estimates resulting from EMERGE modeling of each mission phase. This statistical presentation plots health effects against the total probability that the level of health effects would be exceeded within each mission phase and for the overall mission. The results for Phase 0 and Phase 1 consist of 850 modeling runs for each composite accident scenario within those phases. As noted earlier, each composite accident scenario was modeled using 50 meteorological data sets consistent with a March/April launch from CCAS and the three types of plumes that could result from liquid propellant and/or solid propellant fires in Phase 0 and Phase 1 (liquids only; liquids and STAR 48B propellants; and STAR 48B and GEM propellants). This resulted in 150 combinations within each accident scenario. The results of each set of 150 combinations was then scaled for 17 combinations of source terms and plume configurations to arrive at 850 sets of results (50 meteorological data sets x 17 source term/plume sets) for each composite accident scenario. The Phase 0 curve thus presents the results of the 850 sets of results modeled for the single accident scenario in that phase, while the curve presents the results of a total of 4,250 sets of results for Phase 1 (5 accident scenarios across the three Phase 1 Mission elapsed time segments x 850 sets each). Phase 2 and Phase 3 were modeled using LOPAR as detailed earlier.

Figure 4-1 thus plots 850 health effects estimates for Phase 0 against their associated total probabilities of release and the 4,250 health effects estimates for Phase 1 against their associated total probabilities of release. The curve plotted for the overall mission is based upon all of the modeled results across all phases. Figure 4-1 indicates that the total probability of one or more excess cancer fatalities would be 3.0×10^{-6} or 1 in 330,000.



Source: US DOE 1999

FIGURE 4-1. TOTAL PROBABILITY OF EXCEEDING LEVEL OF HEALTH EFFECTS (EXPECTATION CASE)

Potential land area contamination was evaluated in terms of (1) area exceeding various screening levels (0.1 and 0.2 µCi/m^2) and (2) dose-rate related criteria (15, 25, and 100 mrem/yr) considered by the U.S. EPA, U.S. NRC and U.S. DOE in evaluating the need for land clean-up following radioactive contamination (USDOE 1999). The results indicated that the mean value of land area contaminated at levels exceeding 0.1 and 0.2 µCi/m^2 (the latter being an EPA screening level considered in the risk assessment of previous missions) was less than 0.5 km^2 (0.19 mi^2) for all postulated pre-launch and launch phase accidents, and less than 1.0 km^2 (0.39 mi^2) at the 99th percentile level. The results indicated that dose-related criteria (15, 25, and 100 mrem/yr) could be exceeded in on-site and off-site areas during the first year due primarily to resuspension, but dose rates would fall well below these levels after the first year. Dose rates after the first year would be well below the dose-rate criteria for remedial action. When considered with respect the lifetime risk levels associated with these annual dose rates, the lifetime risk would be well below the U.S. EPA lifetime-risk criterion for which the average annual dose rate criterion of 15 mrem/yr was derived.

4.1.5.3 Health Effects Risk Assessment

From a statistical perspective, the doses received from an accidental release of radioactive material would be predicted to increase the number of excess cancer fatalities in the exposed population. These excess cancer fatalities, referred to as health effects, are calculated based on the collective (population) dose multiplied by a health effects factor (i.e., the number of cancer fatalities per person-Sv (person-rem) of effective dose). Scientific opinions vary on the exact value of excess cancer fatalities per person-Sv (person-rem) effective dose. A value of 5×10^{-2} excess cancer fatalities (health effects) per person-Sv (5×10^{-4} excess cancer fatalities per person-rem) was used (ICRP 1990) and is a representative value for radionuclides that emit predominantly alpha radiation, such as Pu–238 and Cm–244.

To put the estimates of potential health effects for the postulated MS 01 mission accidents into a perspective that can be compared with other human undertakings and events, it is useful to use the concept of risk. Risk is defined by multiplying the total probability of an event occurring with the consequences of that event. Risk, therefore, is the probability-weighted consequence of an event. In the case of potential MS 01 mission accidents resulting in a release of radioactive material, the total probability is obtained by multiplying the probability of the initiating accident by the conditional probability that a release will occur. Risk is then determined by multiplying this total probability for each accident scenario by the associated health effects (excess cancer fatalities) or consequences. The risk estimates have been developed from two perspectives: contribution by mission phase/scenario to mission risk (expressed as health effects) based upon the collective dose and health effects estimates; and average individual risk developed by dividing the mission risk estimates by the exposed population.

A mission risk summary, presented in Table 4-18, estimates the overall mission risk to be 7.4×10^{-5} (0.000074). The risk contribution of Phase 1 accidents (5.5×10^{-5}) represents 74 percent of the mission risk. The primary source of the Phase 1

TABLE 4-18. MISSION RISKS[a]

Mission Phase	Accident Scenario	Total Probability	Mean Health Effects	Risk
0 (Pre-Launch)	On-Pad Fire/Explosion	2.44×10^{-6}	7.78×10^{-3}	1.90×10^{-8}
1 (Launch)				
1a (Liftoff)	On-Pad Fire/Explosion	1.79×10^{-3}	7.74×10^{-3}	1.39×10^{-5}
	Aerodynamic Breakup/Command Destruct System	1.04×10^{-4}	2.02×10^{-2}	2.10×10^{-6}
	Full Stack Intact Impact	4.89×10^{-6}	1.20×10^{-2}	5.87×10^{-8}
1b (Early)	Aerodynamic Breakup/Command Destruct System	1.23×10^{-3}	3.16×10^{-2}	3.89×10^{-5}
	Full Stack Intact Impact	2.53×10^{-7}	7.58×10^{-3}	1.92×10^{-9}
1c (Late)	Aerodynamic Breakup/Command Destruct System	—	—	—
	Full Stack Intact Impact	—	—	—
Phase 1 Combined	—	3.15×10^{-3}	1.76×10^{-2}	5.50×10^{-5}
2 (Pre-Orbit/Orbit)	Sub-Orbital Reentry	2.38×10^{-3}	2.52×10^{-3}	6.00×10^{-6}
3 (Earth Escape)	Orbital-Decay/Prompt Reentry	5.14×10^{-3}	2.52×10^{-3}	1.30×10^{-5}
Overall Mission	—	1.07×10^{-2}	6.92×10^{-3}	7.40×10^{-5}

Source: USDOE 1999

a. Results do not take any credit for intervention or clean-up.

risk is the Aerodynamic Breakup/Command Destruct System composite accident scenario in Phase 1b with outcomes leading to the intact impact of the solid-fueled STAR 48B and attached spacecraft on concrete or sand and the associated burning solid propellant environment.

Although the predicted risks of health effects due to accidents are clearly low, it is still useful to compare the health risks associated with the MS 01 mission to risks encountered elsewhere. One measure of the risk associated with the release of radioactive materials from a mission accident is to estimate the risk to the average exposed individual, or the average individual risk. The average individual risk is defined as the health effect risk divided by the number of persons in the exposed population. This risk is the average risk of a health effect (excess cancer fatality) to a person in the exposed population. The average individual risks are summarized in Table 4-19. The highest individual risks would occur in the launch area due to launch accidents for mission elapsed time less than 38 seconds. The average individual risks in Table 4-19 for each accident scenario in the launch area need to be summed to give the total average individual risk. These average individual risks identified in Table 4-19 are also quite small compared with the commonly faced individual risks. Table 2-9 presents the calculated annual individual risk of fatality by various causes for people within the United States. From all causes, the individual risk is approximately 8.79×10^{-3} per year with disease, accidents, and suicide being the dominant contributors. The average individual risk to persons in the CCAS region from launch of the MS 01 lander/rover spacecraft is estimated at less than 5.50×10^{-10}, which is several orders of magnitude smaller than these other everyday and unrelated annual risks (see Table 2-9).

This level of risk to the regional population is also consistent with the risk levels established by the U.S. EPA and others for potential exposures of members of the general public to hazardous materials that might be released from operations at chemical and nuclear facilities. Standards for routine releases from industrial facilities to the environment have been generally established by the U.S. EPA such that the incremental lifetime risk of cancer to maximally exposed nearby individuals is on the order of 10^{-4} to 10^{-6} due to the operation of a nearby facility. The risks to the regional CCAS population from a MS 01 launch accident are more than a factor of 10,000 lower.

4.1.6 <u>Radiological Emergency Response Planning</u>

Prior to the launch of the MS 01 lander/rover spacecraft with the RHUs and minor radioactive sources on board, a comprehensive plan would be developed in accordance with the Federal Radiological Emergency Response Plan. This plan would ensure that any accident could be met with a well-developed and tested response. The plan would be developed through the combined efforts of NASA, U.S. DOE, U.S. Department of Defense, U.S. EPA, the Federal Emergency Management Agency, the State of Florida, and local organizations involved in emergency response.

Portions of the plan would be practiced to ensure that the various organizations were prepared to support the launch. NASA would be the Cognizant Federal Agency coordinating the Federal response for accidents occurring within U.S. jurisdiction. A walkthrough and command post exercise would occur prior to the launch to ensure that the plan is well-coordinated to ensure a unified response plan in the event of a launch accident.

In the event of a release, or in support of preplanned precautionary measures, the State of Florida and local governments would determine an appropriate course of action for any off-site plans.

A Radiological Control Center located at Kennedy Space Center would coordinate any emergency actions required during the pre-launch countdown or the early phases of

TABLE 4-19. AVERAGE INDIVIDUAL RISKS[a]

Mission Phase	Accident Scenario	Risk	Population at Risk	Average Individual Risk
0 (Pre-Launch)	On-Pad Fire/Explosion	1.90×10^{-8}	1×10^{5}	1.90×10^{-13}
1 (Launch)				
1a (Liftoff)	On-Pad Fire/Explosion	1.39×10^{-5}	1×10^{5}	1.39×10^{-10}
	Aerodynamic Breakup/Command Destruct System	2.10×10^{-6}	1×10^{5}	2.10×10^{-11}
	Full Stack Intact Impact	5.87×10^{-8}	1×10^{5}	5.87×10^{-13}
1b (Early)	Aerodynamic Breakup/Command Destruct System	3.89×10^{-5}	1×10^{5}	3.89×10^{-10}
	Full Stack Intact Impact	1.92×10^{-9}	1×10^{5}	1.92×10^{-14}
1c (Late)	Aerodynamic Breakup/Command Destruct System	—	—	—
	Full Stack Intact Impact	—	—	—
Phase 1 Combined	—	5.50×10^{-5}	1×10^{5}	5.50×10^{-10}
2 (Pre-Orbit/Orbit)	Sub-Orbital Reentry	6.00×10^{-6}	5×10^{9}	1.20×10^{-15}
3 (Earth Escape)	Orbital-Decay/Prompt Reentry	1.30×10^{-5}	5×10^{9}	2.60×10^{-15}

Source: USDOE 1999

a. Results do not take any credit for intervention or clean-up.

the mission. In the event of an accident, a nearby offsite location would be established by NASA, U.S. DOE, U.S. Department of Defense, U.S. EPA and the State of Florida which would conduct radiological monitoring and assess the accumulated data.

The response to launch accidents would also depend on the geographical locations involved. Accident sites within the continental United States and U.S. Territories would be supported initially by the nearest military or Federal installation possessing a radiological contingency response capability. Personnel from all supporting installations would be alerted to this potential requirement prior to launch. Additional support would be dispatched from the launch site support personnel or from other support agencies, as needed. For accidents occurring outside the continental United States or its territorial jurisdictions, the U.S. Department of State and diplomatic channels would be employed in accordance with pre-arranged procedures and support elements would be dispatched as appropriate.

If an ocean or water impact occurs, NASA, U.S. DOE, and U.S. Department of Defense would initiate security measures and search and retrieval operations. The recovery of the plutonium dioxide would be based on the technological feasibility, the health hazard presented to recovery personnel and the environment, and other pertinent factors.

4.2 ENVIRONMENTAL IMPACTS OF THE ORBITER AND LANDER-ONLY MS 01 MISSION ALTERNATIVE

4.2.1 Environmental Impacts of Preparing for the Orbiter and Lander-Only MS 01 Mission Alternative

Spacecraft preparations would occur at both CCAS and VAFB for this MS 01 mission alternative. The environmental impacts of preparing for launch of the MS 01 orbiter and MS 01 lander spacecraft would be as described for the Proposed Action in Section 4.1.1. There would be less radioactive material handled during preparation of the MS 01 lander at CCAS resulting in reduction of the very low occupational exposures expected in preparing for the Proposed Action.

4.2.2 Nonradiological Environmental Impacts of the Orbiter and Lander-Only MS 01 Mission Alternative

As with the Proposed Action, this mission alternative would involve spacecraft launches from both CCAS and VAFB. The environmental impacts of normal launches of the MS 01 orbiter spacecraft and the MS 01 lander-only spacecraft would remain unchanged from those described for the Proposed Action in Section 4.1.2.

Launch accidents have the potential to occur at both CCAS and VAFB for this MS 01 mission alternative. The nonradiological environmental impacts of potential accidents associated with this alternative would be the same as those described for the Proposed Action in Section 4.1.3.

4.2.3 Radiological Consequences and Risks of Mission Accidents for the Orbiter and Lander-Only MS 01 Mission Alternative

The inventory of radioactive materials on board the MS 01 spacecraft for this alternative would be reduced to 1.30×10^{10} Bq (350 mCi) of Co–57, and 7.40×10^{5} Bq (20 µCi) of Cm–242. There would be no Cm–244, Am-241, or plutonium dioxide on board the MS 01 Orbiter and Lander-Only Mission Alternative. The total inventory of radioactive materials on board the lander spacecraft in this alternative would be about 0.3 percent that of the Proposed Action. Given this reduction in the total radioactive inventory of the lander payload, the potential consequences of an accident resulting in a release of radioactive material and the associated risks would be reduced from the already small consequences described for the Proposed Action. The mean estimated health effects across the entire Orbiter and Lander-Only Mission Alternative were estimated at 1.10 $x10^{-5}$ excess cancer fatalities over a 50-year period within the potentially exposed population (i.e., an additional 0.0000110 cancer fatalities) (see Table 4-20). The estimated number of potential health effects associated with a Phase 0 and Phase 1 (Pre-Launch and Launch) accident would be about the same as for the overall mission, 9.93×10^{-6} excess cancer fatalities (i.e., 0.00000993 additional cancer fatalities would be expected over a 50-year period). Thus elimination of the rover and its radioactive material inventory from the lander within this alternative results in a substantial reduction in the already low consequences estimated for the Proposed Action.

The reduction in source terms and potential health effects associated with this MS 01 mission alternative are also reflected in the risks estimated for the mission phases and for the mission as a whole (see Table 4-20). The mean total overall mission risk associated with launch of the MS 01 Orbiter and Lander-Only Mission Alternative was estimated at about 1.18×10^{-7}. This is less than the overall risk estimated for the Proposed Action (7.4×10^{-5}). The risks associated with the individual mission phases would be further reduced. Given the reduction in the radioactive material inventory that would be on board the MS 01 Orbiter and Lander-Only Mission Alternative, the potential extent of land contamination at levels at or above the risk-based screening levels used for comparison in the Proposed Action (see Section 4.1.5.2) would also be reduced relative to the already small area estimated for the Proposed Action. If an accident were to occur, the potential area and levels of contamination would be determined and appropriate response actions initiated.

4.3 ENVIRONMENTAL IMPACTS OF THE ORBITER-ONLY MS 01 MISSION ALTERNATIVE

4.3.1 Environmental Impacts of Preparing for the Orbiter-Only MS 01 Mission Alternative

Only the VAFB launch site would be utilized for launch of this MS 01 mission alternative. The environmental impacts of preparing for launch of the MS 01 orbiter spacecraft would be as described for Delta II launches from VAFB under the Proposed Action in Section 4.1.1.

4.3.2 Nonradiological Environmental Impacts of the Orbiter-Only MS 01 Mission Alternative

The environmental impacts of a normal launch of the MS 01 orbiter spacecraft from VAFB spacecraft would remain unchanged from those described for Delta II launches from VAFB under the Proposed Action in Section 4.1.1.

The potential for launch accidents would be confined to VAFB only for this MS 01 mission alternative. The environmental impacts of potential nonradiological accidents

TABLE 4-20. ORBITER AND LANDER-ONLY MS 01 MISSION ALTERNATIVE CONSEQUENCES AND RISKS[a]

Mission Phase	Accident Scenario	Total Probability	Mean Health Effects	Risk
0 and 1 (Pre-Launch/Launch)	Launch Area	3.15×10^{-3}	9.93×10^{-6}	3.11×10^{-8}
2 (Pre-Orbit/Orbit)	Sub-Orbital Reentry	2.38×10^{-3}	1.16×10^{-5}	2.76×10^{-8}
3 (Earth Escape)	Orbital-Decay/Prompt Reentry	5.14×10^{-3}	1.16×10^{-5}	5.96×10^{-8}
Overall Mission	—	1.07×10^{-2}	1.10×10^{-5}	1.18×10^{-7}

Source: USDOE 1999

a. Results do not take any credit for intervention or clean-up.

associated with this alternative would be the same as those described for VAFB under the Proposed Action in Section 4.1.3.

There would not be any radioactive material on board this mission alternative.

4.4 ENVIRONMENTAL IMPACTS OF THE NO-ACTION ALTERNATIVE

Under the No-Action Alternative, the MS 01 mission would not be implemented, substantially reducing the science returns of the Mars Surveyor Program. Canceling this mission would reduce the ability of NASA to answer questions about Mars' biological history, how it evolved, and its potential for resources.

Termination of the mission would severely jeopardize future in situ missions to Mars. There would be no other adverse or beneficial effects of the No-Action Alternative.

4.5 CUMULATIVE IMPACTS

Contributions of exhaust emissions from the MS 01 launch vehicles would not substantially affect long-term air quality in either CCAS or VAFB region. Launching the MS 01 mission would not cause any changes in land use at or in the vicinity of either CCAS or VAFB.

From a cumulative environmental impact perspective, launch of the MS 01 orbiter from VAFB, and the MS 01 lander/rover from CCAS would principally contribute to exhaust emissions impacts on and near the launch pads. Over the period between May 1995 and January 1998, NASA monitored 46 Atlas, Delta II, and Titan IV launches from CCAS (USAF 1998). Within 70 to 100 m (230 to 330 ft) of the flame trenches, vegetation was scorched and trees were partially or completely defoliated. Deposition of large particulates was found in this area out to about 200 m (660 ft) from the flame trench of the Titan IV launch complex, with small particulate deposition and evidence of low-concentration acidic deposition found between 250 and 830 m (820 and 2,720 ft) from the Delta II launch complex. While these impacts may persist with continued use of a launch site, and the MS 01 launches would contribute to these conditions, they are probably not irreversible. NASA (Schmalzer et. al. 1986) found that vegetation reestablished itself after cessation of launches in similarly affected areas near the shuttle launch pads.

On a short-term basis, the two MS 01 launches would contribute to the addition of ozone depleting substances to the stratosphere. The total contribution of the two launches to the average annual depletion of ozone would be extremely small (about 0.001 percent for each launch on a global annual average basis - see Appendix E).

4.6 ENVIRONMENTAL EFFECTS THAT CANNOT BE AVOIDED

The Delta II main engine and GEMs would be ignited shortly prior to lift-off and would produce Al_2O_3, CO, HCl, and relatively smaller amounts of CO_2, H_2, H_2O, N_2, and NO_X during a normal launch (NASA 1998a). The launch exhaust cloud would be concentrated near the launch pad during the first moments of launch. Thereafter, the launch cloud would be transported downwind and upward.

Biota in the immediate vicinity of the launch pad could be damaged or killed by the intense heat and HCl deposition from the exhaust cloud. No long-term adverse effects to biota would be anticipated at either launch site. Aluminum oxide (Al_2O_3) particulates would also be deposited at the launch site as the exhaust cloud travels downwind.

4.7 INCOMPLETE OR UNAVAILABLE INFORMATION

This DEIS is being developed before final preparations are completed for the MS 01 mission. The primary areas of either incomplete or unavailable information for the MS 01 mission include the following items.

This DEIS evaluates five composite accident scenarios that could potentially result in a release from the RHUs and minor radioactive sources on board the MS 01 lander/rover spacecraft. NASA and U.S. DOE are continuing to conduct testing and to evaluate mission safety and risks. Should any of the ongoing investigations result in risk estimates greater than those presented in this DEIS, NASA will evaluate the new information, consider potential mitigation measures, and make a determination regarding preparation of additional NEPA documentation.

Based on uncertainty assessments performed for previous mission safety analyses (e.g., the Cassini mission), parameter and model uncertainties associated with source terms, probabilities, and radiological consequences could result in risk estimates that vary from one to two orders of magnitude at the 5 and 95 percent confidence levels.

Uncertainty exists in the potential for release of PuO_2 from RHUs if burning solid propellant is nearby. Efforts to further characterize response of RHUs to solid propellant environments are continuing. NASA, U.S. DOE, and their contractors have used the best available information to try to determine the conditional probabilities that a release might occur and the amount and form, especially particle size, of PuO_2 that might be released. Analysis efforts have included hydrodynamic modeling of the effects of propellants under accident conditions and the probable response of the RHUs to the blast, fragment, and thermal environments. This assessment has included study of the January 1997 CCAS Delta II accident that had a spacecraft and a portion of a solid propellant motor land together.

4.8 RELATIONSHIP BETWEEN SHORT-TERM USES OF THE HUMAN ENVIRONMENT AND THE MAINTENANCE AND ENHANCEMENT OF LONG-TERM PRODUCTIVITY

4.8.1 Short-Term Uses

The MS 01 mission would be launched from CCAS and VAFB thus the short-term affected environment would include these two launch sites and their surrounding areas. At CCAS, short-term uses of the area include NASA and U.S. Air Force operations, urban communities, a fish and wildlife refuge, citrus groves, residential communities, and recreational areas (NASA 1995). VAFB short-term uses also include NASA and U.S. Air Force operations, rural communities, a marine ecological reserve, and grazing and agricultural land. Additionally, VAFB and the surrounding area are recognized as a biologically important area that lies in a transitional zone between cool, moist conditions of Northern California and semi-desert conditions of Southern California, and support numerous species of plants and plant communities (NASA 1998a). The MS 01 mission would be conducted in accordance with past and ongoing NASA and U.S. Air Force procedures for operations at CCAS and VAFB launch sites. Should an accident occur at CCAS causing a radiological release, short-term uses of contaminated areas could be curtailed, pending mitigation.

4.8.2 Long-Term Productivity

No change to land use at CCAS and VAFB or their surrounding regions would be anticipated because of the MS 01 mission from LC-17 and SLC-2. The region would continue to support human habitation and activities, wildlife habitats, citrus groves, and grazing/agricultural land. No long-term effects on these uses are anticipated because of the MS 01 mission. However, should an accident occur at CCAS causing a radiological release, the long-term productivity of contaminated land areas could be impacted.

The successful completion of the MS 01 mission could benefit the U.S. space program, which is important to the economic stability of the areas surrounding both launch sites. In addition to the localized economic benefits, implementation of the MS 01 mission has broader socioeconomic benefits. These include technology spin-offs to industry and other space missions, maintaining the unique capability of the U.S. to conduct complex planetary missions by scientists and engineers, and supporting the continued scientific development of graduate students at universities and colleges.

4.9 IRREVERSIBLE AND IRRETRIEVABLE COMMITMENT OF RESOURCES

An irreversible resource commitment results from the use of a resource that cannot be replaced within a reasonable timeframe. The use of a resource that cannot be replaced is termed an irretrievable resource commitment.

For each launch alternative, quantities of various resources, including energy, and fuels, and other materials, would be irreversibly and irretrievably committed. The use of these resources would be associated with the fabrication, launch, and operation of the MS 01 mission.

4.9.1 Energy and Fuels

The fabrication processes for the MS 01 spacecraft would use electrical and fossil fuel energy. This use constitutes an irretrievable commitment of resources but would not impose any significant energy impacts. The launch and operation of the spacecraft would consume solid and liquid propellant and related fluids. The solid propellant ingredients would be ammonium perchlorate, aluminum powder, and HTPB binder. The fluid substances would include RP-1, unsymmetrical dimethylhydrazine, LOX, LH, and nitrogen tetroxide. The quantities that would be used for the MS 01 mission are discussed in Section 2.1.6.

4.9.2 Other Materials

The total quantities of other materials used in the MS 01 mission that would be irreversibly and irretrievable committed are relatively minor. Among the more plentiful of these materials are primarily, steel, aluminum, titanium, iron, molybdenum, plastic, glass, nickel, chromium, lead, zinc, and copper. Less common materials committed to the MS 01 mission include small quantities of silver, mercury, gold, rhodium, gallium, germanium, hafnium, niobium, platinum, and tantalum.